U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
PB-282 806

# Baseline Monitoring Studies, Mississippi, Alabama, Florida, Outer Continental Shelf, 1975-1976. Volume V Geophysical Investigations for Biolithologic Mapping of the MAFLA-OCS Lease Area

State Univ System of Florida Inst of Oceanography, St Petersburg

Prepared for

Bureau of Land Management, Washington, D.C.

28 Jun 75

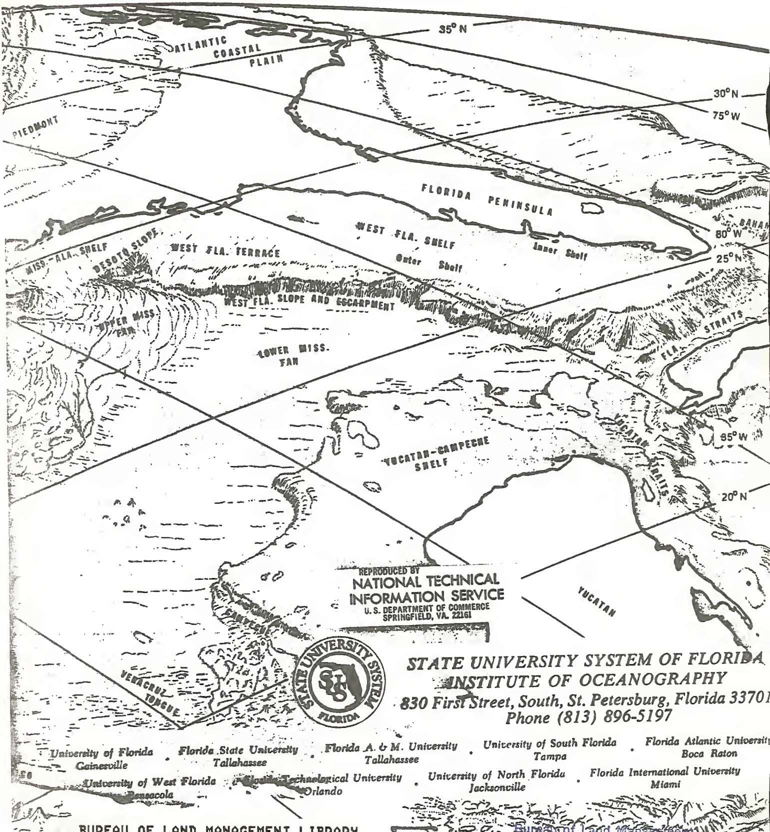
ALABAMA, FLORIDA OUTER CONTINENTAL SHELF, 1975-1976

BLM CONTRACT NO. 08550-CT5-30

VOLUME V

PB 282 806

# GEOPHYSICAL INVESTIGATION






*STATE UNIVERSITY SYSTEM OF FLORIDA*
*INSTITUTE OF OCEANOGRAPHY*
*830 First Street, South, St. Petersburg, Florida 33701*
*Phone (813) 896-5197*

*University of Florida* Gainesville · *Florida State University* Tallahassee · *Florida A. & M. University* Tallahassee · *University of South Florida* Tampa · *Florida Atlantic University* Boca Raton · *University of West Florida* Pensacola · *Florida Technological University* Orlando · *University of North Florida* Jacksonville · *Florida International University* Miami

# NOTICE

| BIBLIOGRAPHIC DATA SHEET | 1. Report No. BLM-ST-78-34 | 2. | 3. Recipient's Accession No. PB282806 |
|---|---|---|---|
| 4. Title and Subtitle "Geophysical Investigations for Biolithologic Mapping of the MAFLA-OCS Lease Area" Volume V, Geophysical Investigation | | | 5. Report Date Accepted June 28, 1975 |
| | | | 6. |
| 7. Author(s) T.E. Pyle, V. A. Henry, J. C. McCarthy, R. T. Giles, and T. W. Neurauter | | | 8. Performing Organization Rept. No. |
| 9. Performing Organization Name and Address State University System of Florida Institute of Oceanography (SUSIO) 830 First Street, South St. Petersburg, Florida 33701 | | | 10. Project/Task/Work Unit No. MAFLA, yr. 2 (1975-76) |
| | | | 11. Contract/Grant No. No. 08550-CT5-30 |
| 12. Sponsoring Organization Name and Address U.S. Department of the Interior Bureau of Land Management 18th & C Streets, N.W. Washington, D.C. 20240 | | | 13. Type of Report & Period Covered Final Report, 1975-76 |
| | | | 14. |

15. Supplementary Notes Volume V of a six volume report. Design of the report is such that Vols. I-IV should be used together, while Vols. V and VI can be utilized independently.

16. Abstracts A multi-sensor geophysical survey including over 3700 km. of high resolution geophysical profiles was completed on the Outer Continental Shelf areas from 26°N latitude to south of Horn Island, Mississippi. On the basis of data collected, the Mississippi, Alabama, Florida (MAFLA) continental shelf area was divided into five major zones on the basis of rock outcrop distribution and dominant sediment texture (i.e., fine, medium, coarse) and into a number of subzones on the basis of textural variability or patchiness. A review is also provided on the bathymetry and shallow structure of the region as well as a summarization of new results of seismic reflection studies on the west-central Florida shelf.



17. Key Words and Document Analysis. 17a. Descriptors

Geological Oceanography, Geophysical Surveys, Bathymetry

17b. Identifiers/Open-Ended Terms Sub-bottom Profiler, Side Scan Sonar, Precision Depth Recorder, Shallow Geologic Hazards, Structures, Karst Topography, Florida Peninsular Shelf, Post-Miocene Sedimentary Framework, Texture Maps, Bedform Maps

17c. COSATI Field/Group

| 18. Availability Statement | 19. Security Class (This Report) UNCLASSIFIED | 21. No. of Pages |
|---|---|---|
| Release Unlimited | 20. Security Class (This Page) UNCLASSIFIED | 22. Price PC A12 MF A01 |

# GEOPHYSICAL INVESTIGATIONS FOR BIOLITHOLOGIC MAPPING OF THE MAFLA-OCS LEASE AREA

-including-

## A Review of the Shallow Structure and Post-Miocene Sedimentary Framework of the Central West Florida Shelf

T. E. Pyle
Department of Marine Science, University of South Florida
St. Petersburg, Florida 33701

V. J. Henry
Skidaway Institute of Oceanography, University of Georgia
Savannah, Georgia 31406

J. C. McCarthy
Department of Marine Science, University of South Florida
St. Petersburg, Florida 33701

R. T. Giles
Skidaway Institute of Oceanography, University of Georgia
Savannah, Georgia 31406

T. W. Neurauter
Department of Marine Science, University of South Florida
St. Petersburg, Florida 33701

ACKNOWLEDGMENTS

We thank Frank Manheim, former chairman of the Department of Marine Science, USF, for his vital role in implementing this study. Jame Gilmore, George LaPiene and Harvey Mason were crucial to the successful completion of our work at sea. We also thank the captain and the crew of the M/V DECCA PROFILER and the navigation party from DECCA Surveys (Houston), especially Mike English, for their hard work at sea and ashore. Able assistance at sea was also provided by A. Chermak, M. Flandorfer, P. Haley (U. of Miami); P. Martinez (Dade J. C.); G. Nash and C. Baker (U. of Georgia).

Assistance in other phases of this study, including a number of cruises on the R/V BELLOWS and R/V HERNAN CORTEZ, was provided by Ginger Gregory and Betty Buckley. We especially wish to thank Capt. Frank Davis and Gene Olson of the BELLOWS and Capt. Frank Wescott and Gary Milano of the HERNAN CORTEZ.

The role of Jim Rein (U. of Miami) in providing the initial interpretations of many of the sonographs from the peninsular platform during the early stages of this investigation, deserves special acknowledgment.

Table of Contents



1E

Table of Contents - continued

Tables

## 1.0 Introduction

Multi-sensor geophysical surveys are common in industry but are usually confined to small areas only a few miles square. Rarely are they applied at one time to an entire shelf and to such a range of water depths and bottom types as in the MAFLA (Mississippi, Alabama, Florida) study and the data reported on in this report are the first side-scan sonar records from the entire Gulf of Mexico to be made publicly available. As a result a number of unexpected and perplexing features have been found. If we are to go beyond mapping and cataloging, we must eventually interpret these features, in fact all our geophysical data, in terms of physical and biological processes. Our own attempts at interpreting some of these sea-floor features in terms of bottom currents and biological communities have made clear a surprising lack of physical and biological field data in our own "backyard". Considering this additional work to be done, we consider this final contract report only a progress report and, hopefully, a catalyst for further integrated work.

Chapter 2 briefly outlines Methods including descriptions of aquisition systems, navigation and operational format.

Chapters 3 and 4 review prior knowledge of the Bathymetry and Shallow Structure of the region and summarize new results of seismic reflection studies on the west-central Florida shelf. The acoustic stratigraphic framework of Mitchum (1976) has been extended to other areas of the shelf and to younger units. These chapters include information on subsidence rates, sediment slumping, cut-and-fill structures, Karst phenomena, terrace development and possible E-W striking faults. The morphology and structural fabric of carbonate banks, including the Middle Ground are used to

infer their genesis. Side-scan sonar profiles are shown to be capable of differentiating and rapidly mapping the epibenthic and textural zones of reefs.

The next two chapters form the basis for the biolithologic map of the MAFLA shelf. The Texture Map (Ch. 5) is based on relative backscattering intensity on side scan sonar records, interpreted with the help of high-resolution seismic profiles. The MAFLA shelf is divided into five major zones on the basis of rock outcrop distribution and dominant sediment texture (i.e., fine, medium, coarse) and into a number of subzones on the basis of textural variability or patchiness. This zonation agrees with results from the limited number of box cores available and, in fact, can explain much of the variability from replicate to replicate. It was concluded that seasonal effects were very difficult to separate from navigation errors or vessel motion in areas of variable bottom.

Correlations of acoustic backscatter with textural grade were generally confirmed by comparison with results of Gould and Stewart (1955), Upshaw, *et al.* (1966), Ludwick (1964), Ludwick and Walton (1957), and McLeroy (1972) in areas of overlapping data.

The response of the seafloor to hydrodynamic forces is revealed by patterns of topographic irregularities known variously as ripples, dunes or sand waves. The presence of such bedforms is a valuable but not unambiguous indicator of areas where waves of currents have affected the sediment and presumably the associated biota. The Bedform Map (Ch. 6) portrays the distribution of three types of features classified on the basis of dimensional criteria proposed by Reineck and Singh (1973) and a fourth type which has been termed "low-relief swells". Although the genesis of most of the observed bedforms is not known, maps of their occurrence may be of assistance in focusing future physical oceanographic

current measurement programs. By indirect reasoning it has been concluded that currents on the order of 50-100 cm/sec were required to produce the majority of large and giant-scale bedforms on the peninsular shelf. These currents are, presumably, related to storms (fronts and hurricanes), tides and, possibly, incursions of the Loop Current in that order of importance. A number of unusual bedform types and eight common types of enigmatic sonar signatures are described and mapped to indicate needs for physical and biological studies of the processes responsible for their formation.

For detailed information on the sites of benthic samples the reader should consult Chapter 7, the Station Atlas where short segments of the side-scan and seismic profiles adjacent to each station are presented. In addition to interpretive sketches of these geophysical profiles brief annotations as to water depth, sediment texture and variability, bedforms and sub-bottom structure have also been provided.

The final chapter, Summary, contains a running list of specific observations, conclusions, suggestions and recommendations from the body of the text.

## 2.0 Methods

Geophysical data acquisition for BLM (Bureau of Land Management) Contract 08550-CT5-30 was conducted between 25 July and 17 August, 1975 during BLM/SUSIO (State University System of Florida Institute of Oceanography) Cruise No. 16 abroad the M/V DECCA PROFILER. More than 3700 km (2300 stat. mi.) of high resolution geophysical profiles were completed. Simultaneous analog data were obtained during continuous operation of the following instrumentation:

1) Subbottom profiler - EG&G Uniboom, towed sled mounted transducer, 300 Joule power supply, EPC 4100 recorder, Del-Norte 502A analog signal processor, bandpass 0.4-1.6 kHz.

2) Subbottom profiler - EDO-Western, hull mounted transducer and V-fin towed fish, EDO 550 recorder, 248C Transceiver, 2000 watt, 3.5 kHz.

3) Side Scan Sonar (SSS) - EG&G dual-channel, 100 kHz, wet paper recorder, deep towed fish (600 m cable), continuous operation.

4) PDR - Atlas DESCO-10, 30 kHz, 300 watt transceiver, hull mount.

During survey operations, the four facsimile recorders were connected to a common event marker controlled by the navigator. The event mark provides a common time reference on all "hard-copy" analog records corresponding to a 305 m (1000 ft.) interval along a preplotted traverse (i.e., 305 m is equal to 1 shot point). Corrections necessary due to positioning of various transducers and receivers relative to the navigation antennae are detailed in the Principal Investigators' Cruise Report - BLM Cruise No. 16.

DECCA Survey Systems, Inc. (DSSI) of Houston, Texas provided all navigation services and details can be found in their report to SUSIO, Hi-Fix Survey Over Eastern Gulf of Mexico, Outer Continental Shelf and Slope (14 pp, plus charts). Selected portions of this report are included in the Appendix.

In summary, all positioning was accomplished with DSSI's Hi-Fix system operating in either range or hyperbolic mode. A DECCA Trisponder system (Model 202A) was utilized for initial lane count acquisition. Preplots and post-plots of positions in Universal Transverse Mercator (UTM) coordinates were generated on-board the survey vessel with an Autocarta X-Y plotter system. Corrected post-plot positions were tabulated and charted by DSSI for every tenth navigation point (32,808 m).

Theoretical accuracy is stated in the DSSI report to be ±0.015 lanes (or ±2.5 m in range-range mode with a minimum 30° angle of intersection). Skywave or electrical storm interference may have resulted in errors of ±0.2 lane (or ±35 m).

A copy of the tabulated UTM coordinates and corresponding latitude and longitude is included in the Appendix. Figures 1, 2 and 3 are reduced copies of the track chart originally plotted by DSSI at a scale of 1:250,000 (Traverse Mercator projection, UTM grid, Clark Spheroid of 1866). This plot also includes reference to latitude and longitude based on North American Datum - 1927. The choice of scale reflects the format which the National Ocean Survey (NOS) is using for preparation of new bathymetric charts of the Gulf of Mexico. It should be noted that all positions on Figs. 1, 2 and 3 are referenced to 87°W longitude which is the central meridian of UTM Zone 16 (90°W to 84°W).

In addition to the geophysical data acquired on BLM Cruise No. 16, approximately 4700 km (2900 stat. mi.) of continuous high-resolution seismic reflection data were reviewed for this report. These data were collected on the west Florida platform between 1972 and 1975 under the supervision of Dr. T. E. Pyle, University of South Florida, St. Petersburg. All surveys were made with a 300 Joule Uniboom system similar to that used in the contracted survey. Positioning was provided by LORAN-A with an estimated accuracy of ±0.2 to 0.8 km. The "pre-existing" Uniboom profiles within the study area are plotted on Fig. 4. The Corresponding navigation-time series for this plot is tabulated in the Appendix.

## 3.0 Bathymetry

### Introduction

The shelves and adjacent coastal plain of the Gulf of Mexico have been the focal point of considerable investigative effort by geologists and geophysicists, especially during the last two decades. A recent bibliography published by the Gulf Coast Association of Geological Societies lists more than 12,000 titles pertinent to the geology of the Gulf region (Braunstein, 1970). Summaries of various aspects of the geology of the MAFLA region, including additional bibliographic information, can be found in Antoine (1972), Emery and Uchupi (1972), Wilhelm and Ewing (1972), Pyle and Antoine (1973), Brooks (1973), Antoine et al., (1974), Uchupi (1975), and Martin and Case (1975).

Despite the volume of published information, considerable gaps still exist in our knowledge of the geology of the eastern Gulf, particularly regarding details of the sedimentary framework, shallow structure and late Cenozoic history of the west Florida shelf. Several reasons can be enumerated for this including a lack of economic impetus for research at a level comparable to that which initiated and supported many of the programs on the northern and western Gulf of Mexico shelves. It is also true that the interior portions of carbonate shelves commonly present difficult conditions for the application of standard seismic reflection profiling techniques which provide the basis for most of the knowledge of the sedimentary framework of submerged coastal plains in the absence of well control. On the west Florida platform, the problems encountered during seismic investigations are compounded by the subtlety of the structures, the size of the area and distance from onshore stratigraphic control. The size of the shelf and a general absence of major relief features has also obscured many important details of the physiography. Much of the

available bathymetric data lacks the necessary precision in geographic control that is a requisite for detailed geomorphic analysis.

Chapters 3 and 4 outline the present state of knowledge of the shallow structure and physiography of the peninsular(1) and northern(2) shelves and summarize the results of high-resolution seismic reflection investigations conducted during the last four years by the University of South Florida.

3.1 Bathymetry - Peninsular Shelf

New compilations of bathymetric data from the MAFLA shelf were obtained during the past year from the National Ocean Survey (NOS). Under a separate contract with the BLM, the NOS has begun the preparation of a series of maps at a scale of 1:250,000 and with the depths contoured in meters (every 2 m to a depth of 200 m and every 10 m in deeper water). Most sheets in this series covered 2° of longitude and 1° of latitude. Although few or no new data are included in these maps, and they rely upon data obtained as long ago as the mid-19th century, they are the best shelf-wide bathymetric maps publicly available and are a valuable contribution to understanding shelf processes.

The SUSIO study area and six benthic transects were to have been covered by twelve of the planned sheets. Of these, four have been published in full color (Mobile and Mobile South together, Pensacola and Destin Dome), four are available in preliminary form (Middle Ground, Gainesville, Tarpon Springs and St. Petersburg) and four have not been completed. For

(1) The "peninsular" shelf in this report refers to the portion of the study area between 26°N and Cape San Blas (i.e., West Florida shelf)
(2) The "northern" shelf refers to the study area between Cape San Blas and Horn Island Mississippi. (i.e., the Mississippi, Alabama and Florida panhandle shelf).

the latter four areas (Appalachicola, Big Elbow, Ewing and Charlotte Harbor), "equivalent" maps were prepared by enlarging portions of the "Bathymetric Maps Eastern Continental Margin, U.S.A., Sheet 3, Northern Gulf of Mexico". This map (A.A.P.G., 1970) was published at 1:1,000,000 scale with depth contours in fathoms (contour interval 1 fm. from 0-50 fm, 2.5 fm from 50-75 fm and 5 fm from 75-100 fm). After enlargement with a Map-O-Graph, metric contours were interpolated by hand. The value of the substitute product was further dimmed by large data gaps in the original AAPG (American Association of Petroleum Geologists) map. Two of these gaps were along two of the six benthic transects (numbers 1 and 4). To compensate for lack of control on these transects, bathymetric profiles were constructed from PDR data taken during the geophysical cruise. These are presented in the Geological section of this report.

The quality of the data used in NOS compilations is highly variable due to differences from survey-to-survey in precision of horizontal positioning and depth measurement, and the earliest data are not necessarily the worst. Variations in sounding density, as shown in the map legends, are reflected on the charts by comparable variations in topographic complexity. Unfortunately, these might be interpreted as representing differences in bottom type, bedform development, wave and current regimes, etc. The contouring style used on these maps is unusual and closed highs tend to be convex outward while closed lows are convex inward.

Closed lows may result from several processes, but on a carbonate platform they may be indicative of sink development due to karst processes. Only areas not filled due to meager sediment supply, or having sufficiently active discharge in the recent past to prevent accumulation, would be apparent on the bathymetry. Assuming that no feature smaller than 1.59 mm

would be contoured on the NOS sheets, any closed low would have to be more than about 400 m in diameter. This is larger than most of the features detected on high-resolution seismic profiles that we have attributed to karst dolina development (see dimensional analysis of negative structures on the west Florida shelf in "Karst" section). The detection of smaller features on the NOS sheets is further complicated by limitations imposed by sounding density; the profile spacing often being in excess of 1 km.

All major karst trends detected on our high-resolution seismic profiles were filled and blanketed by unconsolidated sediments. Subaerial exposure of bare limestone tends to retard karstification; case hardening being a common result. Maximum rates are often associated with development of a shallow free flowing aquifer with infiltration of organic acids from decayed vegetation speeding up the process. Closed lows, large enough to be accurately defined on the bathymetric sheets, and extremely low gradient slopes can be used to delineate areas where karstification is most probable.

Closed highs were studied to obtain clues which might indicate trends of shoreline processes, shallow shelf sediment transport, bottom-current interactions, etc. The contour interval of 2 m may not be small enough to fully delineate the subtle features present on most of the west Florida shelf and, in many areas, line spacing is probably inadequate to map even the largest bedforms (see Bedform Maps Section). Obvious trends were apparent on the Cape San Blas shelf, off Tampa Bay and in the Big Bend region. One of the better developed trends which was not apparent on earlier bathymetric compilations was the ridge and swale topography present on the outer shelf southwest of the Middle Ground reefs, between 70 and 90 m isobaths. (see Middle Ground sheet, NOS NH 16-12). If these are relict and represent

shifting sand shoals during the last regression, they explain the termination of the linear coral-algal ridges to the north and south (see Texture Maps - Discussion and Conclusions).

An unusual feature on the bathymetric sheets are the "railroad tracks" or elongate, east-west striking "notches" and offsets which trend normal to the contours several places on the peninsular shelf. These are present on both AAPG and NOS maps suggesting they are not the result of contour style. However, this occurrence on both charts may be due to a common data base and offsets in survey tracks resulting from navigation errors, although the number of occurrences would seem to preclude the latter. All have the same east-west strike and some, especially those at about 28°30'N, are reflected far to the west as offsets in the face of the west Florida escarpment. The lack of seismic profiles normal to these features hinders speculation on their origin at this stage. Inshore, they may conceivably be shore, relict, unfilled channels that developed normal to the slope, similar to the coast-normal drainage character of the Big Bend coast between Tampa Bay and Apalachee Bay. However, their persistence across the shelf to the slope, and their unusual linearity suggest a common structural origin.

Larger morphologic elements of the shelf have been discussed in a number of studies. The more important of these are Jordan (1952), Jordan and Stewart (1959), Ballard and Uchupi (1970) and Bergantino (1971). Important recent reviews can be found in Emery and Uchupi (1972), Brooks (1973) and Uchupi (1975).

The highest order morphologic elements on the west Florida shelf are the major terraces. Bergantino notes two principal terrace trends at 64 m-82 m and 100 m-120 m. Careful scrutiny of the NOS maps, particularly the Florida Middle Ground, Tarpon Springs and Gainesville sheets, suggests other terraces between 40 m and 20 m, although development is not always

apparent due to the extremely low shelf gradient landward of the 60 m isobath. The principal break in slope on the platform tends to be less pronounced to the south and second outer break is apparent south of about 27°30'N. This break corresponds to a change in escarpment and slope characteristics at about the same latitude.

Most of the second order morphology of the platform is due to the presence of relict carbonate buildups which reflect late Quaternary eustatic events. Ballard and Uchupi (1970) subdivide the west Florida shelf into three relict shoreline provinces: 160 m shoreline-outer shelf, 60 m shoreline-middle shelf and the relict and modern inner shelf.

The deeper province is dominated by a system of elongate banks which Ballard and Uchupi believe represent relict spit-lagoon complexes. These are best defined between 140 and 160 m , although occurrences are noted to 180 m. The subbottom profiler data obtained in 1975 suggests that those encountered within the study area are in-place skeletal accumulations (banks) that are covered by a blanket of silty sand which preserves some of the original relief. An example can be seen on Fig. 5 at n.p. (navigation point) 5.7 (see Carbonate Buildups - peninsular shelf). No structural evidence was observed which suggest that these structures are hydrodynamic buildups (i.e., spits).

The 60 m shoreline province of the middle shelf is dominated by a series of south striking spurs that Ballard and Uchupi refer to as ridge and valley complexes. The best developed of these structures is "The Elbow" which is defined by the 60 m isobath between 27°45'N and 28°N. Subbottom profiles across these structures suggest that they are primarily hydrodynamic in origin with associated secondary coral-algal ridge and pinnacle development (see Fig. 6).

Seaward of the spits are a number of more subtle relief features which subbottom profiles indicate to be a buried complex of superimposed constructional ridges, terraces and reef-like structures. These tend to predominate to depths of about 110 m, probably indicating maximum long term eustatic lowering during the last major regression (Fig. 7 n.p. 1-3.5). Pinnacles and linear coral-algal ridges are also common at the surface and the major trends of these are outlined in the Acoustic-Texture Maps section of this report. Most of these trends were noted in previous studies (e.g., Jordan and Stewart, 1959) although side-scan sonar allows detection of the more subtle features.

North of the ridge and valley complexes that dominate the 60 m relict shoreline south of 29°, are two relict cuspate forelands and deltas that occur south and west of the Cape San Blas shelf. Uniboom crossings in the vicinity show relatively thick, seaward prograding, clinoform slopes that are usually composed of two or more distinct acoustic units. Each unit probably represents a major Pleistocene regressive - transgressive sequence.

The relict and modern nearshore province of the inner west Florida shelf exhibits only two prominent relief features: the Florida Middle Ground reef complex and the linear sand shoals seaward of Cape San Blas. The Florida Middle Ground reefs are described elsewhere (see Texture Map and Carbonate Buildups - Florida Middle Ground). The reefs are the most prominent relief feature of the Florida shelf within the study area. Examples of profiles across portions of the reef are shown in Figures 8, 9 and 10. The linear shoals are discussed in the Bedform Map section and have been described by a number of investigators including Schnable and Goodell (1968) and Swift (1973). Swift considers the shoals to be

an intermediate stage of an estuarine shoal-retreat massif which he terms a "cape-shoal retreat massif" and as such, the morphology of the features would bear little relationship to their original form. Sonar evidence of large and small scale bedform development on the flanks of the major ridges suggest that hydrodynamic process are still actively modifying these structures. However, major changes probably occur only in response to unusual storm-induced conditions (see Bedform Maps - Discussion and Conclusions, peninsular shelf).

The balance of features on the shelf are too subtle to be mapped without much greater control and sounding precision.

3.2 Bathymetry - Northern Shelf

The physiography of the northern shelf and upper slope is relatively simple. A well developed buried topography, probably Beaumont/Prairie Pleistocene deposits, extends down to near the 55 m isobath. From Horn Island to Mobile Bay, the sediments of the St. Bernard prodelta and those derived from the Pascagoula River and Mobile Bay have been deposited in sufficient amounts to produce a nearly flat, smooth bottom. From Mobile Bay eastward the influx of sediments has not been sufficient to bury the pre-Holocene topography, leaving an area with an irregular-hummocky surface. Southeast of Mobile Bay a group of features resembling an ancient bay, barrier island and lagoon are seen along the 32 m contour (Ballard and Uchupi, 1970). The outer shelf and slope apparently have received little sediment in modern times.

To the east the shelf off Panama City exhibits features which may be relict topography from nearshore to about midshelf. From here to near the shelf edge and southward to Cape San Blas the shelf is characterized by fields of varying size sandwaves. The largest area of giant sandwaves

is present off Cape San Blas. Sand shoals in this zone are typical of other cuspate forelands such as Cape Hatteras and Cape Canaveral (Shepard, 1960).

The northern end of DeSoto Canyon is an asymmetrical depression with much steeper slopes on the western side. Both the sides and floor of the canyon margin are smooth except for pinnacle zones that occur around the canyon margin at depths of 68-84 m and 97-110 m (Ludwick and Walton, 1957).

## Results of High-Resolution Reflection Profiling of the Peninsular Shelf

### 4.0 Review of Structure and Sedimentary Framework

Before examining more recent geologic development of the west Florida platform, it is important to consider the regional structure and sedimentary framework of the MAFLA region. In this and the following sections it should become apparent that a number of geologically recent structural and stratigraphic trends tend to be associated with similar ancient trends. Winston (1969) alluded to this tendency when he observed that present day reefs occurred on gravity anomalies believed to be caused by pre-Mesozoic basement highs. Critical evaluation of previous work is beyond the intended scope of this review and would be superfluous in light of recent papers by Antoine et al. (1974) and Martin and Case (1975).

Antoine (1972) subdivides the Gulf of Mexico region into seven geologically distinct provinces. The MAFLA investigation covers an area which includes portions of three of these provinces: (1) the Northern and (2) Northeastern Gulf of Mexico shelves and (3) the South Florida shelf and slope (see Fig. 11).

The Northern Gulf of Mexico shelf (province 1, Fig. 11) is dominated by one major structural element, the Gulf Coast Geosyncline. This

positives. Conclusive evidence regarding the origin of the Destin anticline has yet to be published; it is currently thought to be due to either deep seated igneous activity (Antoine et al., 1967) or nonpiercement salt tectonics (Antoine, 1965).

Martin (1972) has suggested that the Florida Middle Ground Arch is probably related to the same tectonic movements that resulted in the Peninsular arch. He also indicates that the arch may be "...more a product of differential subsidence than of active upwarping." The concept of "negative tectonism" was also favored by Goodell and Yon (1960) as the dominant mechanism influencing most of the late Tertiary structural-stratigraphic trends of Florida. The three isolated highs along the east-west trend of the Florida Middle Ground Arch (Figure 12) may be products of stratigraphic thickening of Upper Cretaceous carbonates similar to that noted in Lake City strata which results in the Ocala "uplift" (as mapped by Vernon, 1951; cf. Winston, 1976). Winston prefers to call the latter structure a "blister dome" because it is underlain by strata which do not exhibit the same structural closure.

It appears that some confusion may be in the process of developing regarding the definition of the Middle Ground Arch. Winston (1969) designated a broad east-west positve Jurassic structural trend north of the South Florida Basin as the Middle Ground Arch. The structure maps which Winston uses to define the arch are really sketches (lacking geographic coordinates) and the contours suggest a very broad trend with a lobe extending southwest from the main east-west trend on the outer platform. A strong, positive magnetic anomaly was observed by Heirtzler et al. (1966) to strike southwest along the same trend. This plus the refraction and reflection data, allowed Antoine (1972) to detail features of the northern component of the structure. He then referred to it as

the Ocala Extension but in a more recent published work (Antoine, et al., 1974) referred to it as the Middle Ground Arch in accordance with Martin (1972), Garrison and Martin (1973) and Winston (1969). In a 1975 review of the physiography of the Gulf of Mexico and Caribbean region, Uchupi designated two separate east-west trending structures: (1) the northern is referred to as the seaward extension of the Ocala Arch and (2) the southern, the Middle Ground Arch (see Uchupi, 1975; Figure 17 and p. 21). Uchupi proposes that these structural axes flank a large filled re-entrant on the outer west Florida terrace postulated by Krivoy and Pyle (1972) on the basis of gravity data. Although the axes, as designated by Uchupi, approximate the northern and southern extremities of the broader structure described by Winston, the southern margin was originally indicated as striking southwest, rather than west, forming the northwest margin of the South Florida basin (Winston, 1969; Pyle and Antoine, 1973). On the basis of evidence cited by Uchupi, there seems little reason to indicate the trend as two separate structures, as both Winston and Antoine were apparently referring to the same positive trend. We prefer to designate the structure as the Middle Ground Arch on the basis of precedence and wider usage and to disassociate any implied relationship with the Ocala anomaly.

More important than the developmental history of the Middle Ground Arch, is its effect on the post-Cenozoic stratigraphy of the west Florida carbonate platform. Refraction data and lithostratigraphic analysis of both slope and coastal plain strata indicate that the arch provided a barrier to clastic deposition in the South Florida Basin during most of the Cenozoic (Martin, 1972; Antoine and Harding, 1965; Mitchum, 1976). Barriers to southeast growth of the clastic embankment were also provided by the Suwanne Straits (Hull, 1962; Chen, 1965; Applin and Applin, 1967;

Martin, 1972) and DeSoto Canyon (Harbison, 1968; Mitchum, 1976). Recent seismic-stratigraphic investigations on the northeastern Gulf slope (Mitchum, 1976) suggest that the western lobe of the Middle Ground Arch has been relatively positive throughout the Cenozoic; the thickness of Neogene slope strata increases immediately north and south of the arch.

Province 3, the west Florida platform south of the Middle Ground Arch, is dominated by the South Florida basin. Seismic reflection and refraction data, correlated with onshore well control, have suggested that this basin has subsided more than 4600 m since Late Jurassic - Early Cretaceous time. A thick sequence of shallow water carbonates and evaporites has accumulated in the process (Antoine and Ewing, 1963; Pyle and Antoine, 1973; Oglesby, 1965; Antoine et al., 1974).

Seismic reflection data, dredging of the west Florida escarpment and onshore wells indicate that a lower Cretaceous algal reef flourished along the escarpment, forming a structural rim that restricted circulation sufficiently to induce cyclic evaporite deposition in the South Florida basin to the east (Uchupi and Emery, 1968; Bryant et al., 1969; Garrison and Martin, 1973 and others). This reef trend is more or less continuous in the subsurface around the northern and western perimeter of the Gulf of Mexico coastal plain as far south as the Gulf of Campeche (Figure 11). It may have connected with reefs of equivalent age in Cuba and eastward to the Bahama Banks prior to development of the Straits of Florida. Investigations have also produced evidence for contemporaneous reef development on the Campeche escarpment in the vicinity of Catoche Tongue. The absence of the reef structure in most seismic reflection profiles across the Florida escarpment south of 27°N is attributed to widespread erosion and faulting of the platform margin (Antoine and Pyle, 1970; Pyle and Antoine, 1973).

The axial trace of the South Florida Basin is approximated on Figures 11 and 12. Exact definition is subjective, depending on continuity, quality and nature of the data base and on the horizon contoured. Different interpretations can be seen in structural maps prepared by Winston (1969), Pyle and Antoine (1973) and Emery and Uchupi (1972). For the most part, variations are due to a lack of adequate control defining southern and southwestern closure in the Mesozoic section.

Figure 13(a) is a cross section through peninsular Florida to Cuba (Martin and Case, 1975). This section diagrammatically illustrates the basic sedimentary framework of the Florida carbonate platform and, with the possible exception of poorly developed Mesozoic basin closure on the outer margin, is essentially analogous to a north-south shelf section through province 3.

Figure 13(b) shows the velocity structure across the Campeche and west Florida platforms (Martin and Case, 1975). Evident are the shelf margin reefs that provided structural closure throughout the Cretaceous. Termination of reef development and thinning of the Cenozoic section suggest that the South Florida basin ceased to be an important negative structural element during the Tertiary. Stratigraphic analysis of Tertiary deposits on peninsular Florida indicates that active downwarping of the carbonate platform south of the Middle Ground Arch continued at least through Miocene (Goodell and Yon, 1960; Chen, 1965). Differences in elevation of the crest of the lower Cretaceous reef trend south of the Middle Ground Arch indicate that the magnitude of net subsidence on the outer margin is on the order of 2-3 cm/1000 yr, with the southern margin subsiding at a somewhat greater rate (+0.5 cm/1000 yr Pyle and Antoine, 1973). Our own observations of a possible late-Middle Miocene shelf margin reef indicate a net rate of subsidence of about 3 cm/1000 yrs

on the upper slope south of the Middle Ground Arch. Both estimates approximate the range of 2-3 cm/1000 yrs proposed by Emery and Uchupi (1972; Figure 324, p. 434) for the west Florida platform.

With the exception of the preceding generalities, little additional structural or stratigraphic information is available for the shelf in province 3. The most complete picture of the post-Cretaceous development of the west Florida platform is found in Mitchum's (1976) seismic-stratigraphic study which concentrated on the transition zone to the north (province 2). Mitchum's stratigraphic interpretations are based on analyses of deep cores correlated with regionally prominent discontinuity surfaces present on seismic reflection profiles (100 KJ sparker source). Velocity corrections, based on prior common depth point data, allowed construction of a series of isopach maps of depositional sequences bound by these regional discontinuities. Lack of core data and inferior quality of seismic data restricted his investigation to the slope between the DeSoto Canyon and about 26°30'N.

Figure 13(c) is an example of an interpreted dip section across the slope from Cape San Blas to the DeSoto Canyon. On it the general relationships of most of the acoustic-stratigraphic horizons recognized by Mitchum are apparent. A prominent feature of the section is the contrast between the relatively horizontal beds below surface "F" (top Oligocene-lower Miocene) and the overlying beds that dip to the west and terminate on "F" by offlap. This seismic boundary was characteristic of all profiles and corresponds to an upper Miocene - Oligocene /lower Miocene faunal hiatus present in the cores. The sequences above "F" are dominated by a thick wedge of middle and lower middle Miocene deposits. More recent units tend to occur as lenses filling irregularities in the clinoform slopes formed by the thick prograding wedge of

middle and lower middle Miocene sediment.

Mitchum's isopach maps show that all post-middle Miocene sequences are thinner or absent over the Middle Ground Arch suggesting that it was a prominent structural element affecting shelf development to the south. Mitchum reports that sediments in deep slope cores show a systematic decrease in terrigenous clay content to the south. Terrigenous material is almost totally absent in the southernmost samples despite increased clastic influx into the Apalachicola marginal embayment to the north during the Miocene.

North and south of the arch, the middle Miocene sequence thickens markedly. Axes of maximum accumulation represent laterally prograding clinoform features thought to correspond to the middle Miocene shelf margin. Isopach maps show that upper Miocene through Pleistocene deposits tend to occur in lenses built out on the middle Miocene clinoform slopes. Net accumulation of these strata was greatest on the outer slope and, to the north, along the southern margin of the Apalachicola embayment.

Localized thickening of Neogene strata suggests increased subsidence of the southern salient of the Apalchicola embayment, especially during the Miocene. Subsidence probably increased in response to increased downwarping of the Gulf Coast Geosyncline to the west during the same period. It was interesting to note that maximum middle Miocene accumulation occurs south of the Middle Ground Arch, on the outer shelf margin, and approximates the location of the anomalous crustal block reported by Krivoy and Pyle (1972). Lack of data to the south precludes closure of the isopach contours, but possible relationship of the two anomalies is difficult to dismiss as merely coincident.

## 4.1 Post-Miocene Sedimentary Framework

Although the major structural elements and developmental history of the west Florida platform have been outlined, with the exception of Mitchum's recent (1976) analysis of the slope stratigraphy southeast of DeSoto Canyon, previous investigations have provided few data applicable to detailing post-Miocene events. High-resolution seismic (Uniboom) reflection profiles from the University of South Florida acquired during this investigation, combined with previous USF data, provide an extensive data base from which to examine the more recent geologic history of the west Florida shelf. Figure 4 is a track chart showing historical "Uniboom" coverage of the west Florida shelf north of 26°N.

High-resolution subbottom reflection profiles are more normally applicable to detailing the acoustic fabric of specific near-surface structures or the acoustic-stratigraphy of more geographically restricted areas than the west Florida shelf. This is due to a number of reasons, the most obvious resulting from the relatively low penetration. Acoustic discontinuity surfaces detectable with high frequency systems often represent subtle changes of impedance contrast due to local rather than regional phenomena. Consequently, one often observes more striking lateral than vertical contrasts limiting regional projection unless control is dense or the signatures are particularly diagnostic or are of known origin. Despite these shortcomings for regional reconnaissance applications, high-resolution profiles are the only existing data base available for the study of the more recent history of the west Florida platform. Published seismic investigations reviewed in the previous section (Review of Structure and Sedimentary Framework) generally provide no data from the upper 30 to 50 meters, which includes most of the post-Miocene section. In addition, lower frequency investigations rarely allow observation of

any of the subtle characteristics of a reflector which are useful for interpretation in the absence of stratigraphic control.

Figures 14, 15, 5 and 11 are line tracings of Uniboom profiles which illustrate the acoustic character of the outer west Florida shelf and upper slope south of 29°N. Regionally prominent reflectors are provisionally correlated with Mitchum's (1976) acoustic-stratigraphic horizons A, B, C and D which represent the top of Pliocene, upper Miocene, upper middle Miocene and middle middle Miocene strata respectively (cf. Figure 13c). In addition, a prominent reflector present in the Pleistocene section on the outer shelf is labeled $A_1$. The latter corresponds to the base of the upper two Pleistocene sequences common on the shelf and is probably pre-Wisconsin in age. Strata above and below $A_1$ are referred to as upper and lower Pleistocene respectively.

Profiles U-4 and U-5 (Figure 14), the northernmost of the representative sections, are characterized by a relatively narrow zone of shelf margin buildups, a sharp break in slope at 4/4 and 5/5 (i.e., U-4, navigation point (n.p.) 4 and U-5, n.p. 5) and pre-Pleistocene units that exhibit moderate angular discordance.

Thickness [(1)] of the total post-Miocene (post-B) section ranges from about 50 msec., seaward of the shelf break, to less than 15 msec. at the eastern end of the sections. Correlations with Mitchum's isopachs suggest Pliocene strata pinch out just seaward of both profiles. A maximum total Pleistocene thickness of about 80 msec. is indicated at the shelf margin on Figure 14 at 5/5.5.

---

(1) Thicknesses and depths in this section refer to 2-way travel time in milliseconds (msec); assuming C=1,500 m/sec., 1 msec.= 0.75 m.

The upper Pleistocene sequence is characterized by a complex of seaward prograding structures on the flank of the buildup (e.g., at 5/4-5 and 4/4.5) and some minor terracing at depths between 130 and 150 msec.

Internal structure at the shelf break is suggestive of a complex of in-place organic proliferation (more predominant on U-4) and hydrodynamic rearrangement (see following section Carbonate Buildups). Miocene strata offlap and/or are truncated along B. The upper Miocene unit pinches out at 5/8.5 and another strong reflector was detected at the eastern end of both profiles. This reflector may correspond to C (top of upper middle Miocene?) which is more prominent on profiles to the south.

The unusual near surface structure at 4/6, at a water depth of 160 msec., may be a shelf margin skeletal buildup overlain by 5-10 msec. of low impedance unconsolidated sediments. The depth is similar to that noted for the more well developed shelf-margin banks to the south (cf. Figs. 5 and 15).

The combination of profiles U-10 (Figure 15) and U-11 (Figure 7) extend from just east of the shelf break to the upper slope. The most obvious contrasts with profiles U-4 and 5 (Figure 14) to the north are the greater breadth of the zone of shelf-margin buildups, lack of angular discordance of the pre-Pliocene units and the anomalous thickness of post-A units.

Post-Miocene thickness of these profiles ranges from a maximum of about 150 msc at 10/3.5 to about 20 msec at 11/8. The upper Pleistocene sequence (post $A_1$) betweeen 10/6 and 10/7.5 appears to be dominated by shelf-margin in-place organic buildups. From 10/8 to 11/6.5, a complex series of predominantly seaward prograding structures dominate,

although some east dipping strata are present. These structures occur in three distinct sequences bounded by locally prominent acoustic surfaces.

The structure between 11/5.5 and 11/6.5 is a section normal to a north-south trending spur-like ridge known locally as "The Elbow". An abrupt scarp (about 7 msec. high) defines the seaward edge of an algal ridge developed along the margin of this feature. The pre-Pleistocene sequence is characterized by off-lapping strata. The unit bounded by B and C (upper Miocene?) appears to terminate at about 10/8. Another strong reflector terminates at about 10/4 and this is thought to represent the top of Pliocene strata. East of 10/4 the ruggedness and higher reflectivity of reflector B may indicate indurated shelf sands on the outer margin of the upper Miocene shelf. Structures at 10/5 and 10/4 are both suggestive of carbonate bank development, although the returned signal looses much of its ability to characterize details after penetrating a sequence this thick. The lowest reflector, detected between 10/6 and 11/1.5, may correlate with Mitchum's surface "C" (top of upper middle Miocene).

Profile U-15 (Figure 5) is similar to the previous example in many respects except that the Plio-Pleistocene units apparently overlie older Miocene strata. Mitchum's isopach maps indicate that upper middle Miocene and upper Miocene strata are absent at this locality. Upper middle Miocene units may lap on D at about 15/8.7 on the seaward flank of a small anticlinal structure thought to represent a Miocene shelf edge reef. Maximum post-Miocene thickness is about 140 msec. at 15/7 and 15/5.7. Between 15/8 and 15/4.3 a wedge of Pliocene (?) sediments is evident; maximum thickness being about 50 msec. at 15/7/

Shelf margin buildups are prominent in post-$A_1$ units between 15/1

and 15/6 and consist of a variety of different types. The post $A_1$ sequence, between 15/4 and 15/6, is dominated by buried bank-like structures suggestive of in-place organic proliferation (see following section - Carbonate Buildups). Between 15/3.5 and 15/2, a complex of hydrodynamic type buildups is dominant. At about 15/1.1, a 7 msec. scarp defines the seaward edge of a relict algal ridge that extends about 30 km to the north (cf. Figures 28 and 30). Between 15/4.5 and 15/3.5 pinnacle reefs are present at the surface. These are part of the same large belt-like trend previously described and mapped on the Acoustic-Texture maps (Figures 28 and 30). The "lumpy" reflector just below the surface between 15/4.8 and 15/5.6 may indicate similar features buried under a thin blanket of Holocene sediments.

Units underlying D show foreset bedding between 15/5 and 15/7. Seaward and underlying the slight rise evident on the same surface between 15/7.5 and 15/8, are features that probably represent Miocene shelf margin buildups; the most interesting aspect being the small anticlinal structure on the seaward flank. If this last structure represents a shallow shelf bioherm, then net subsidence of the shelf at this locality has been approximately 300+ m since late middle Miocene, or about 3 cm/1000 yr., which agrees with rates proposed by Emery and Uchupi (1972) and estimates from data presented by Pyle and Antoine (1973). This would tend to support the tentative late middle Miocene interpretation for surface D, using somewhat circular reasoning.

The thick sequence of low impedance, post-Miocene sediments on the upper slope shows evidence of down-slope movement seaward of 15/6.3 (Figure 5). The most recent slumping is apparent at the bottom-water interface; a rather large compressional elevation being apparent at about 15/8 (Figure 5). These structures are discussed in a later

section.

Profiles to the south are similar in character to U-15, differing primarily by the increasing dominance of shelf margin organic banks in upper Pleistocene strata similar to the example at 15/5.5 (Figure 5) and the absence of the anomalously thick wedge of Plio-Pleistocene strata on the upper slope. The latter structure corresponds to a local anomaly shown on Mitchum's isopach of Pleistocene strata (see Mitchum, 1976; Figure 16).

Profiles on the shelf landward of the shelf break show few structures and the pentration was generally low. The structures that were detected can be generally described as filled negative anomalies resulting from karst, channel and valley development. These are analyzed in more detail in the section on Karst. Examples of profiles on the inner shelf can be seen on Figures 16, 8 and 17.

Seaward Extension of the Central Florida Barrier Coast

Figure 17 is interesting in that it represents a portion of a major valley complex which developed west of Tampa Bay on the inner shelf in an area that we refer to as the "seaward extension of the central west Florida barrier coast". This area is characterized by large, well developed deeply incised and filled valley complexes; the most striking example being the very large system west of Tampa Bay. The area designated "E" on Figure 18 outlines the location of this valley complex. The excellent definition in the north is attributed to its deep incision into the underlying limestone which is a very effective reflector. One of the important aspects of this system is the morphologic similarity to the major west coast estuaries of Tampa Bay and Charlotte Harbor. Like these estuaries, the major valleys of of the updip portion exhibit dendritic north-south drainage

development which ultimately trends to the southwest toward the open Gulf. The upper tributaries of this complex are completely filled with stratified sediments (up to 30 msec. thick on Figure 17) while the southern portion appears to be incompletely filled although subtle, terraces noted on the new NOS bathymetric maps between about 20 and 30 m suggest a relatively long still-stand of sea level at these depths.

The existence of a number of strong reflectors within the thick fill implies a number of sequential depositional cycles indicative of a complex development history. The source of filling sediments, judging from the location and number of feeding tributaries, was probably to the north and east. The sediments may be largely composed of terrigenous materials derived from late Miocene siliclastics deposited around the flanks of the Ocala-Middle Ground positive. It was also noted that the lower reflector which defines the structure is locally cut deeper than any observed connecting "Gulfward" outlet. This may be due to a number of reasons including locally higher rates of solution, increased stream competency due to changes in cross-sectional area of the channel and variations in bed competency. Probably all three have played a contributing role, the dominant process varying with relative sea level. The controlling depth was commonly noted to be about 70 and 80 msec (2-way travel time) which would be equivalent to a minimum of 50 to 60 m below present sea level. It seems unlikely that any strictly fluvial system that may have developed on the central west Florida shelf would have been competent enough to erode valleys that deep unless regressions associated with continental glaciation were of longer duration or of much greater magnitude than is currently suggested (Galloway, 1970). We propose that tidal-inlet processes similar to those that produced the 27 m deep channel north of Egmont Key at the mouth of Tampa Bay cut parts of these

paleovalleys to the depths observed.

From Tampa Bay to Charlotte Harbor other, perhaps similar, large, deep valley complexes were detected but they are less well defined. A continuum of cut and fill structures, similar to migrating spit or point bar sequences, and channels are locally interrupted by divides. The central barrier coast extension generally exhibits unconsolidated sediment thickness greater than 10 msec and often up to 50 msec or more in larger filled valleys. Outcrops have been reported by divers and fishermen although our limited side scan sonar control suggests they are relatively uncommon except seaward of Venice, Florida (see Texture Maps - Subzone III (b), Figure 30). The western boundary of the "extension" is poorly defined south of Tampa Bay due to sparse seismic control. It appears that the proposed siliclastic valley fills may grade seaward into predominantly bioclastic carbonates. The latter show less stratification on the profiles and the impedance contrast is either low or the strong basal reflector is too deep or poorly developed to be easily identified on the records.

## Isopach Map of Post-Miocene Strata

The only regionally prominent acoustic horizon that was sufficiently continuous to map, was the top of the Miocene. This horizon is shown on Figures 14, 15 and 5 as surfaces B, C and D, from north to south respectively. In other words, this acoustic discontinuity defines the top of upper Miocene deposits in the vicinity of profiles U-4 and U-5 and the top of middle Miocene in the vicinity of U-15. Uniboom data acquired previous to the MAFLA-OCS study consistently penetrated the total post-Miocene sequence on the outer shelf and upper slope between 27° and 29°N. Boomer data acquired in this investigation were commonly of lower quality and did not penetrate this sequence due to high background noise caused by higher profiling speeds. Consequently, little additional

control was added to the existing data base except on the shelf north of the Middle Ground region. Mitchum's data indicate that Plio-Pleistocene strata thicken markedly north of 29°N, so higher energy seismic systems might be required to extend control to the north.

Structural contours of the Miocene surface show few trends that deviated from the present shelf-slope surface. South of 28°N, the strike is more easterly on the shelf suggesting either lower rates of deposition and/or higher rates of subsidence to the southwest. Both would be consistent with observations from other investigations.

One notable structural anomaly was the prominent buried "terrace" at depths of 325 m and 350 m, between 27°N and 28°N on the upper slope. This is the same platform that is characterized by the "warped" C and D reflectors noted on line tracings of U-10 and U-15 (Figures 15 and 5).

Figure 18 is a raw-time "isopach" map (contour interval 10 msec.) of the post-Miocene section. It primarily represents Pleistocene strata, although some lenses of Pliocene sediments are present in thicker sections. The wedge of anomalously thick post-Miocene units overlying the terrace is well defined by the contours between 27°N and 28°N, seaward of 84°30'W. West of 85°W, the section thickened rapidly, pinching out on the lower slope at the escarpment (Mitchum, 1976).

The genesis of this filled structural anomaly is problematical. Late-Miocene sedimentation rates were apparently sufficient to fill in other surface irregularities that may have developed elsewhere on the outer shelf and upper slope. Local steepening of the slope, on the seaward flank of the Miocene terrace, suggests the possibility of reconstructing the surface to conformable proportions if rotational slumping or very low angle faulting is assumed. No clear evidence for such movement is present in our data aside from the geometry. Higher penetration reflection

data might provide such evidence. It is interesting to note that the heads of the two largest slumps apparent on profile U-15 (Figure 5) overlay the area of maximum displacement, suggesting a possible trigger mechanism for the slumps if faulting occurred.

This structural depression does overlie the trend of "anomalous-crust" proposed by Krivoy and Pyle (1972) based on gravity data. Perhaps differential subsidence has accentuated the structure. Whatever the origins, all anomalously thick Plio-Pleistocene sequences on the outer shelf and slope north of 28°N should be expected to contain geotechnically weak strata if the descriptions of deep cores are indicative of their character (unpublished USGS open file core data). Exploratory stratigraphic test wells drilled by Exxon and others commonly encountered strata consisting of silty-sands described as being very soft or "soupy". This type of deposit has also been found in association with large scale slumping on low gradient slopes of the New Zealand platform (Lewis, 1971).

In general, post-Miocene strata are less than 10 msec. thick over the eastern trend of the Middle Ground Arch (cf. eastern "dome" along the trend of the arch on Cretaceous structure - Figure 12). On the shelf south of the arch the thickness increases from 10 to 40 msec. On the outer shelf, thickness ranges from 30 to 80 msec.; small anomalies being common due to local skeletal buildups. North of the arch the complete Plio-Pleistocene section was not penetrated except for a few data points east of 85°N. These few data suggest that isopleths trend to the east, indicating thickening of strata in the Apalachicola marginal embayment to the north.

All of these trends are consistent with the trends of basement structures previously described north of 28°N, and support the previous

suggestions of others (notably Winston, 1969 and Goodell and Yon, 1960) that the lithostratigraphic and structural aspect of the Florida platform continues to be influenced by pre-existing structural trends and negative tectonics.

The source of the materials comprising the thick wedge of sediment filling the structural anomaly developed on top of Miocene strata on the outer platform south of the Middle Ground Arch is not known. It seems reasonable to assume that they are composed primarily of unconsolidated carbonates derived from the shelf to the northeast. Boomer profiles, correlated with Mitchum's acoustic-stratigraphic units, indicate that most of the filling was accomplished during the Pliocene which would require late Miocene-early Pliocene downwarping of the slope and/or uplift of the platform to the east. The angular unconformity of Miocene reflectors on U-5 and U-4 (Figure 14) would be consistent with late Miocene or Pliocene deformation on a regional scale. Control, however, is sparse considering the size of the areas affected and additional strike profiles are required on the outer shelf seaward of the shelf break to clarify details of the acoustic-stratigraphy and related structure.

4.2 Carbonate Buildups - Dominant Types

Trends of major reefs[1] and pinnacle reef distributions will be described and discussed in the Texture Map section of this report. Based on internal structure and morphology, we have tentatively classified the

(1) "reef" is not utilized in the restricted sense in this discussion but refers to structurally closed carbonate buildups exhibiting topographic relief and differing in acoustic fabric from surrounding equivalent strata. In other words, reef is used in a stratigraphic sense (see Heckel, 1974).

larger carbonate accumulations into three general types (modified after Heckel, 1974):

1) large skeletal buildups - predominantly in-place organic proliferation;
2) large skeletal buildups - predominantly hydrodynamic rearrangement;
3) small skeletal buildups - organic proliferation in-place.

This classification is employed since it allows genetic inferences based only on the observed structural fabric and morphology, and does not require knowledge of the skeletal constituents. Larger skeletal buildups in acoustic-texture Zone II (Fig. 30) often exhibit internal structure characteristic of both types 1 and 2; as a consequence, differentiation can be difficult despite the simplicity of the classification. There is another complication to interpreting the genesis of skeletal buildups on the peninsular shelf, i.e., karst-induced morphology (chemical weathering). Karstification has been proposed as the dominant process controlling the morphology of some reefs (Purdy, 1974). Our observations suggest that karst-induced reef morphology is probably significant only on the Florida Middle Ground reefs, and is of limited significance seaward to about 120 m, and is not of perceptible significance seaward of 120 m (120 m approximates the maximum lowering of sea-level during the most recent regression).

The best known of the large carbonate buildups in Zone II (Figure 30) are the Florida Middle Ground reefs. Because of their special importance to the MAFLA-OCS baseline study they are discussed separately in the following section.

Seaward, and south of the Florida Middle Ground reefs, at a depth of 50 to 70 meters, another class of large skeletal buildups occur. These are the six north-south trending "spur-like" ridges that are morphologically analogous to spits developed adjacent to headlands on

barrier coasts. Their morphology has suggested to various investigators (see especially Ballard and Uchupi, 1970 and Jordan and Stewart, 1959) that these ridges represent relict "spit and lagoon" complexes that developed during the most recent glacio-eustatic cycle. Although their planimetric aspect suggests they are southward prograding type 2 skeletal buildups, many of our seismic reflection profiles show areas of poorly developed irregular-lenticular internal fabric suggestive of type 1 dominance. The largest of these spurs is located approximately due west of Tampa Bay and is locally referred to as "The Elbow". The morphology of this buildup is well defined by the 60 m isobath on the "Big Elbow" quadrant. This feature was crossed a number of times on previous seismic cruises conducted by the University of South Florida group. The most enlightening profile is a north-south transect along the lower strata were primarily of type 2 origin (dipping southward) and the shallowest unit was dominated by in place growth (see sketch, Figure 19a).

The mixed character of "The Elbow" is probably representative of the other five spurs - that is, the primary structure is of hydrodynamic origin, probably a spit of barrier-bar developed during relatively stable lowered sea level. When the bar or spit was overstepped during a subsequent transgression, the topographic relief and substrate provided favorable conditions for in-place organic proliferation. Side-scan sonar profiles of other ridges, to the south along this same trend, suggest that coral-algal incrustation and pinnacle development was the norm during the last evolutionary stage of these buildings.

South of 28°N and seaward (between 140 and 200 m) is another series of north-south trending ridges, some of which also have a "spur-like" aspect. The internal structure of these ridges suggests that they are

type 1 platform margin skeletal buildups that were only slightly modified by hydrodynamic processes (evidence for the latter is suggested by their elliptical aspect with the long axis subparallel to the bathymetry). The majority of the ridges crossed were blanketed by 10 to 20 msec. of thinly bedded low impedance sediments which are commonly thicker on the crest and seaward flank. Examples of the internal fabric of these buildups can be seen on Figure 5, between navigation points 5 and 6, and on Figure 20, at "X". The thicker crest deposits suggest that the primary relief may have provided a favorable site for higher rates of accumulation after conditions were no longer favorable for the types of organisms that comprise the matrix of the original structure (see sketch, Figure 19b). Hydrodynamic processes may have been responsible for redistribution of the overlying loose skeletal blanket downslope, on the seaward flank, preserving some of the relative relief and linear aspect of the original structure. These features do not have any of the structural attributes that would suggest they were the product of any shoreline processes during a previous sea level still-stand at 160 m as proposed by Ballard and Uchupi (1970). In the example shown on Figures 20, the total thickness of the matrix of the buildup is about 12 m. Rates of carbonate production of modern coral reefs are estimated to range from a norm of about 0.6 to 1.0 m/1000 yrs. to a maximum of 3.0 to 5.0 m/1000 yrs. (Smith and Kinsey, 1976). Mathews (1974) suggests a range of about 0.1 to 1.0 m/1000 yrs. is a normal rate for carbonate accumulation in shallow water. Applying these estimates to the example, it would have required from 3000 to 120,000 yrs for the buildup to develop with a best estimate of 12,000 to 20,000 yrs. The latter figures suggest that these features could have formed during one regression. The thickness of the overlying sediment blanket suggests that it may have developed prior to

the last regression. Our reflection records indicate that any still-stand lower than 100-120 m during the last major regression was of insufficient duration for larger shore-zone constructional features to have developed or they were obliterated during the subsequent transgression.

Type 3 carbonate buildups are represented by pinnacle reefs on the outer shelf and patch reefs and individual coral heads on the inner shelf. The occurrence of coral-algal pinnacles on the outer west Florida shelf has been previously noted by Jordan and Stewart (1959) and published details of similar features from the northeastern Gulf of Mexico can be found in Ludwick and Walton (1957) and Ludwick (1964). We encountered pinnacles on the majority of transects seaward of the shelf break; although, as previously noted they often occur on bathymetric highs landward (e.g., they commonly cap the linear ridges between 50 and 70 m). To the north they are best developed at depths of 70 to 100 m adjacent to the relict cuspate foreland and deltas southwest of Cape San Blas. Other concentrated occurrences were noted at depths of 75 to 85 m, seaward of the major "spit-lagoon" complexes (at 50 to 70 m), and are presumed to be contemporaneous with their development. The deeper trend between 120 and 150 m between 27°N and 28°N is shown on Figures 28 and 30. In this zone, pinnacle concentrations ranged from a few to as many as 900 per $km^2$ (the average being a few hundred per $km^2$) and the relief of individual pinnacles varied from barely detectable to 5 m. An example of these features, as they appear on sonar data, can be seen on Figure 21. They can also be seen on the line tracing of U-15 near navigation point 4.5 (Figure 5). Pinnacles having the greatest relief tended to occur seaward of the major population concentration (see sketch, Figure 19c).

An interesting aspect of the last two types of buildups is their evolution on the outer shelf on top of low impedance strata (carbonate muds?). Careful scrutiny of U-15 (Figures 5 and 20) indicates seaward continuation of the irregular pinnacle surface (at about n.p. 4.5) beneath the blanket of carbonate mud. This surface may represent buried low-relief type 3 buildings. Initial colonization and pinnacle development might ultimately lead to coalescence and, under continued favorable environmental conditions they would evolve into major shelf edge banks. This may be the genesis of the matrix structure of the large banks common between 140 and 180 m on the outer shelf south of 28°N. Types 2 and 3 "hard" targets (see later section on Unidentified Targets) may be an incipient stage of such an evolutionary cycle.

## 4.3 Florida Middle Ground

The most prominent carbonate buildup on the west Florida platform north of the Florida Keys, and the only example of high relief hard substrate in the study area, is the Florida Middle Ground reef complex. The bathymetry of these reefs was first mapped by Jordan (1952) and they have been the subject of only a few subsequent geologic investigations (Brooks, 1962; Back, 1972).

The morphology is dominated by two parallel ridges, which strike approximately north-south, and a "plug-like" reef structure which separates the two ridges at their southern terminus. The steepest slopes are developed adjacent to the flat central inter-reef plain which is bounded by the three main relief structures and open to the north. Maximum relief is about 15 m.

Figure 22 is a reduction of an enlarged base map (scale 1:80,000) as modified from Jordan's map. The contour interval is one fathom.

A number of reconnaissance crossings during earlier Uniboom surveys

of the region indicated that the eastern ridge is developed along the strike of the seaward margin of a Tertiary limestone terrace which dips seaward under the western ridge. The limestone surface, seaward of the terrace, shows striking "karren-like" karst development. This is evident on profiles U-8 (Figure 9b) and U-7 (Figures 9a and 8) which cross the eastern ridge south of the main trend. We refer to this area as, the "southern extension" of the eastern ridge.

The southern extension is a lesser known portion of the reef complex which exhibits very dissected pinnacle-like development (see U-7, n.p. 6.5 - Figure 9a and U-8, n.p. 4.5 to 5.5 - Figure 9b). These pinnacles tend to terminate at about 35 m with a common base at about 40 m. Both of these depths correspond to weak discontinuity surfaces noted on profiles along the western ridge (e.g. BU-17, Figure 10). The 40 m depth corresponds to the depth of the base of the southern portions of all three main relief features.

The pinnacle-like character of the prominences of the southern extension are probably the result of both karstification during emergence and secondary growth after subsequent transgression. Both the morphologic character on profiles (e.g., U-8, Figure 9b) and the closed depressions evident on bathymetric maps suggest karstification. Purdy (1974) considers karst processes to be dominant control on the morphology of Pleistocene reefs having a history of emergence.

Bathymetric trends and high resolution seismic profiles indicate that the western bank developed on a southward prograding spur which is defined by 36 m isobath on Figure 22.

The only known radiometrically dated sample was from a core taken on the crest of the east ridge (Brooks personal communication to Back, 1972). A carbon-14 date of about 6000 years before present suggested

a net accumulation rate on the order of 0.3 m/1000 yrs which agrees with the lower rate proposed by Smith and Kinsey (1976).

The structural fabric of the Florida Middle Ground reef complex suggests that its present relief is dominated by in-place organic proliferation with karstification contributing to some of the secondary morphologic details apparent in the bathymetry. Karstification appears to be restricted to the east ridge, southern extension and the "plug reef". In general the reefs are unstratified except for a few weak subbottom reflectors which probably represent two or more breaks in deposition (subserial exposure?).

Some evidence of hydrodynamic control of development was noted on the profiles at the southern terminus of the west ridge and at the northern end of the east ridge, suggesting that the linear nature of the ridges may have been the result of intensive current activity.

Back (1972) reported strong currents (ca. 100 cm/sec) on the crest of the reefs during periods of strong thermocline development and suggests that these are the result of tidal forces. Troughs are developed at the base of both the east and west ridges below the level of the central plain and the presence of coarser sediments suggests they may be the result of scour (Back 1972).

Our own sonar profiles along the west ridge show ripple development in the coarse skeletal sands which are present on portions of the reef crest (Figure 4). These ripples strike north-south, suggesting either east or west flowing currents. Well developed fields of northeast - southwest striking closed "shoals", evident on bathymetric maps, tend to strike north-south in the vicinity of the reefs (see Florida Middle Ground and Gainsville quadrants, NH16-12 and NH17-7). These may be indicative of the predominent direction of near bottom water movement (east or west across the crest). The plug reef development at the

southern terminus of the two main ridges suggests such movement may be to the south if, as Jordan (1952) proposes, it has developed on a channel-divide.

Side scan sonar profiles along the crest of the reef also detected faunal zonations. Consultation with Dr. T. S. Hopkins (Univ. of Alabama) who conducted the dive program on the reefs, suggested that sonar studies would be an effective tool for mapping major epibenthic zones if adequately supplemented by ground-truth. In this instance, even at low resolution (ca. 1 m) reconaissance ranges, we were able to differentiate between the fringing Millepora zone, the Gorgonian-Sponge flats and faunally impoverished areas on the reef crest (Figures 41 and 23). We were also able to identify aprons of reef talus and sediment textural variations in adjacent "off-reef" areas. Microtopography attributed to both biogenic and hydrodynamic processes were observed (i.e., mounds associated with bioturbation-burrowing and ripples).

Sonar crossings of other relief features seaward of the reef complex suggest that they are also capped by "hard" reef-like growth (see sections on Texture Maps and Unidentified Targets, type 5 bottom). The present benthic program is restricted to the main relief features; however with respect to area, the southeast extension is an important component of the reef complex and should be characterized, at least at the reconaissance level in future studies.

Although the Florida Middle Ground reef complex has received considerable attention from other programs as part of the MAFLA-OCS baseline study, documentation could be improved considerably by revising bathymetric control and conducting additional sonar studies directed at mapping major epibenthic faunal zonations. Both objectives, it augmented by ground truth from a coordinated diver/dredge program and

underwater CCTV, would result in more quantitative characterization of this ecologically important region.

4.4 Shallow Geologic Hazards - Karst

Identification and mapping of shallow structural features, principally evidence of near-surface faulting and karstification, was one of the objectives specifically outlined for the 1975 geophysical reconnaissance. High-resolution subbottom profiling of the peninsular shelf resulted in no convincing evidence for near-surface faulting. Consequently, most of our attention has been directed toward mapping major karst trends.

Reflection records alone offer few unequivocal clues for assigning a specific genesis to a particular structure. In the case of a structural depression developed on a reflecting horizon that is defined by an isolated profile, one cannot always readily differentiate between a channel, doline, simple basin or, for smaller features, velocity anomalies. However, consideration of the dimensional characteristics and bedding subtleties of the sediment fill, in the context of the regional geologic setting, often allows subjective assignment of a process-oriented interpretation with a reasonable level of confidence by comparison to modern and ancient analogs. A closely-spaced grid of profiles would be required to better determine three demensional character and azimuths thereby confirming such inferences.

Utilizing 3.5 kHz and Uniboom subbottom profiles acquired from the region originally assigned to the University of South Florida group in conjunction with historical Uniboom data, negative structural anomalies were catalogued and mapped. In addition, measurements of apparent width and depth (assuming c=1500 m/sec) were made where possible. More than 300 of these depressions were sufficiently well defined to enable assignment

of a simple form index by calculating the ratio of apparent width to depth (W/D). Perhaps in the future a more diagnostic measure, such as cross-sectional area, could be determined to characterize variations in the morphology of the depressions. Further refinements at this stage were rejected due to the statistically poor sample which resulted from survey restrictions and objectives (i.e., lack of regularly spaced, normally oriented, high-density transects).

Figures 24 (a) and (b) are bar graphs of width and W/D respectively vs. population. Superimposed on each are the associated cumulative percent curves. Cursory examination of Figure 24 (a) suggests the existence of a population with three modes at approximately 76 m, 518 m and 3048 m. Roughly, an order of magnitude separates the apparent mode of each population suggesting that a natural division may exist. These modes correpond to morphologically distinct classes of structures which may also be the result of different processes.

The plot of population vs. W/D, Figure 24 (b), also exhibits a polymodal character with graphic modes at about 10, 40 and 170, although the first two (at about 10 and 40) overlap sufficiently that they might be treated as one skewed population. The lack of a distinct break in this case is understandable when one considers that the cross-section of a solution doline and a small stream channel incised into a similar limestone are probably dominated by the same chemical processes, differing only in rate of solution and three-dimensional morphology. A similar analogy could be made for stream channels vs. tide-dominated channels developed in non-cohesive sands. Although the genesis is dissimilar, the dimensional characteristics in one plane can be identical and there may be no apparent transition from one type to another in a mixed population.

In Figure 25, width (W) is plotted against the corresponding width-depth ratio (W/D). On the graph, information is designated according to source:

> Solid dots - data from 3.5 kHz profiles (1975 survey-profiles 12 through 33).
>
> Open squares - data from Uniboom profiles (1975 BLM survey - profiles 12 through 33).
>
> X's - date from pre-existing Uniboom profiles (USF data).

The resulting plot appeared to be simple power function so, assuming its form to be $\log W/D = a_1 \log W + a_0$, the regression coefficents were calculated. The resulting equation, $W/D - 0.46\ W^{0.75}$ is represented by the broken line on Figure 25. The high correlation coefficent of 0.91 is probably due to the fact that the majority of the anomalies noted and measured were from a geologically similar region, i.e., an exposed to thinly veneered carbonate shelf.

Although the divisions are more subtle, one can again note the tendency of the data to be clustered into three major populations. The smallest features as a group, (left hand side of Figure 25 - $W/D < 20$, $100' < W < 400'$) exhibit the greatest deviation from the calculated regression function. These structures most commonly occur on the inner shelf between Tampa and Apalachee Bays (the "Big Bend" region). Their morphology and occurrences will be discussed in more detail later, but it should be pointed out that in most cases their assigned depths are minimal due to obscuring side echoes which cause abrupt changes in relief to appear on the records as parabolic traces. In a significant number of cases these structures may be considerably deeper. Therefore, assuming accurate width measurement, the plotted values might deviate even more from the calculated regression line. One the other hand, the larger structures, may of which probably represent elongated basins or channels,

would have assigned width values that are too high if the measure profiles are not normal to the channel axis. The net effect, if both these discrepancies could be corrected, would be a regression function that can be visualized by rotation of the plotted function, on Figure 25, clockwise about a point at approximately W/D = 20 and W = 200'.

Specific details of the graphs in Figures 24 and 25 are not that important at this stage. The primary objective in presenting them is to illustrate the range in dimensional characteristics encountered and some of the difficulties involved in interpreting the origin of such structures based only on two dimensional character. The data can be partially summarized as follows:

1) Apparent width of all closed negative structures ranges between 15.2 and 12.192 m Width/depth ranges from 5 to 1,100. The considerable spread in gross dimensions and the polymodal character of the combined data suggest that these structures represent more than one morpho-genetic type. In contrast, the high correlation coefficent for the regression equation of all W vs. W/D data suggests that some dominant or common geologic factor (e.g., bedrock lithology) is involved in the process.

2) Infra-regional variation of W/D as a function of W was observed to be minimal while maximum deviation from the major trends usually correlated with apparent changes in local geology (i.e., bedrock vs. non-cohesive vs. cohesive substrate). These deviations suggest the possibility of inferring local substrate geology from channel morphology.

3) Regression coefficients calculated from width and depth data derived from 3.5 kHz and Uniboom profiles were very similar ($W/D = 0.39\ W^{0.79}$ vs. $0.39\ W^{0.76}$ respectively). However, this study vs. historic Uniboom data differed considerably ($W/D = 0.39\ W^{0.79}$ vs. $1.38\ W^{0.59}$ respectively) suggesting that either sampling density (seismic repetition rate) or navigation accuracy (horizontal control) were more important than instrumentation in this case. The principal value of the 3.5 kHz profiles is in resolution of structures smaller than 30.5 m across; the Uniboom system better defines wider and deeper structures. Structures smaller than 15.2 to 23 m in width were difficult to detect with either seismic system. If such resolution is necessary, slower profiling speed and narrower beam sound sources and receivers must be utilized in conjunction with higher repetition rates.

The foregoing analysis of the dimensional characteristics of negative structures on the peninsular shelf, and the habit of occurrence of various types suggest that the majority of the smallest (dimensionally) modal group of measurable structures were karst dolines. These were usually less than 60 m in diameter and have W/D ratios of approximately 10 or less. These structures almost always occurred in the Big Bend region between Tampa Bay and Apalachee Bay and two major trends were noted. These are designated on Figure 18 as $D_1$ and $D_2$. $D_1$ is the inner karst zone which is defined on only one transect; there is no nearby control to the north or south. However, the depth of occurrence (approximately

15 to 25 m) coincides with undocumented reports of sinks and possible discharging springs in adjacent areas. $D_2$ is better defined and appears to be an 8 to 11 km wide belt trending north-south for approximately 80 km parallel to the 30 m isobath. Figure 16 is an example of a profile across one of these doline fields. With the exception of a few isolated occurrences, most of the doline-like features were observed in trends $D_1$ and $D_2$, and were filled and veneered by a thin blanket of unconsolidated sediments.

The apparent absence of doline structures further north may be the result of regional differences in the Tertiary limestones. North of 29°N, in the vicinity of profiles 24 and 25 (Fig. 2), it is probable that the upper limestone grades into more terrigenous strata (Yon, 1966; Antoine and Harding,1965; Schnable and Goodell, 1968; Vause, 1959; Yon and Hendry, 1972). This may account for better developed surface drainage and lower susceptibility to karstification.

A large, well developed, deeply incised, filled valley complex was noted west of Tampa Bay ("E" on Figure 18). This was part of a special investigation in which extensive seismic profiling was conducted with a Uniboom system (Pyle _et al._, 1975). Initial impressions, on earlier reconaissance crossings, were that the region was highly karstified. Subsequent analysis of later data acquired further south showed the structures to be a major valley system analogous to present embayments that are developed along the west coast of peninsular Florida (e.g., Tampa Bay, Charlotte Harbor). The northern portion of the complex is deeply incised into a Teritary limestone substrate and the deepest reflectors often indicate karstification to be present. This is apparent at "K" on Figure 17.

The only other major shallow trends indicative of karst development

on the west Florida terrace are the very dissected karren-like surfaces designated "K"$_1$ and "K"$_2$ on Figure 18. These occur in belt-like trends which strike north-south subparallel to the bathymetry. $K_1$ extends approximately 190 km parallel to the 40 m isobath and is locally 20 km wide. On our Boomer profiles the surface is characterized by extremely rugged relief, resulting in a somewhat smeared record on some profiles. This is exemplified on Figures 8 and 9. This signature is suggestive of a very dissected or "karren-like" limestone surface. The majority of the depressions noted were too small to be defined by measurement but are believed to be similar to the limestone pinnacles described by Vernon (1951). These are commonly associated with phosphate deposits of northern peninsula Florida on the east flank of the so-called Ocala "Arch". Even though the records suggest the surface is composed of isolated pinnacles, one should note that they occurred below the projected altitude of the surface on which they are developed. If the relief was due to coral-algal accumulation one would expect a more positive aspect relative to the projected structural trend. The karren-like trend, $K_1$, is blanketed by 5 to 20 msec of sediments which pinch-out or are truncated just landward of the Middle Ground reef complex.

The $K_2$ trend is a similarly dissected karren-like surface which also trends north-south subparallel to the bathymetry. This belt may be 100 km in length and up to 10 km wide. Although the surface does not appear as highly dissected as $K_1$, a similar relationship appears to exist between occurrence and overlying sediments. That is, the overlying unit pinches-out or thins just landward. Possibly the overlying sediments were the updip of recharge zones of a shallow aquifer which flanked the adjacent limestone structures. Infiltration at this point, by chemically active surface run-off, would tend to accelerate solution locally. Another

possibility is that these zones may have developed at sites of discharge of ground water along the flank of the adjacent structural or morphologic highs. In the latter case, increased solution rate is caused by increased flux of active ground water at the points of discharge, while the former is both the site of increased flux and "new" water which might be expected to be more active. Like many of the paleomorphic features observed on the shelf, it seems possible that both processes may have played dominant roles dependent on the relative position of sea level. A third possibility is that these surfaces were at one time shallow shore zone terraces that were subjected to intertidal chemical weathering (Reville and Emery, 1957). The $K_2$ trend does appear to be further seaward than one might expect active shallow karst development to be during the late Pleistocene (assuming a maximum low stand at about 120 m). One would need to consider the age of these features and the possible effects of long term downwarping of the outer shelf before proposing a specific genesis.

4.5 Unstable Slopes

Unstable or mobile sedimentary strata were noted on three Uniboom profiles from the outer shelf and upper slope and the occurrences are designated on Figure 18 as $S_1$ and $S_2$. Both were coincident with thick accumulations of post-Miocene sediments that fill upper and upper middle Miocene structural depressions (Mitchum, 1976).

Evidence from deep cores on the slope suggest that the sediments occurring in these thick fills commonly consist of "soupy" silty sands (Mitchum, 1976 and unpublished USGS open file core data). The low apparent slopes (less than 1°) precludes oversteepening as a mechanism. Figure 20 shows examples from profile U-15. These structures, designated "S", may be the result of "creep" more than slumping.

Lewis (1971) describes similar features on the New Zealand continental

slope. These were considerably more extensive but, interestingly, they also occurred in silty-sands. Lewis cites evidence for earthquakes as a trigger mechanism. We can suggest no similar mechanism although, if these are the result of gradual creep, no trigger for abrupt failure is required.

In the examples on Figure 20, the areas involved may be on the order of serveral square kilometers but, due to the thin units affected, the tensional depressions at the head and compressional elevations at the toe are not easy to define precisely. The two largest slumped units have almost coincident head and toe locations and they overlie a flexure in the basal unit which was discussed in prior sections. If, in fact, the underlying units are actively subsiding or rotational movement has taken place, then the two structural anomalies may be related.

Descriptions of slope cores suggest that slump structures may be common on the outer shelf and slope north of 28°N. However, such structures are generally difficult to detect in strata having low impedance contrast due to the masking of the low amplitude reflections by relatively high noise levels. This was a particular problem during the survey conducted as part of this investigation due to the high profiling speeds necessitated by survey time constraints. Most of the BLM-Boomer profiles did not even detect internal bedding in the same areas due to degradation of records by high background noise. In some instances this may have been due to amorphous internal acoustic fabric caused by slumping or creep.

## Results of High Resolution Reflection Profiling - Northern Shelf

### 4.6 Introduction

The northern shelf is that portion of the northeastern Gulf of Mexico between Cape San Blas, Florida and Horn Island, Mississippi. The three largest divisions of the northern shelf are the Mississippi-Alabama-West

Florida Panhandle shelf, DeSoto Canyon, and the Florida Panhandle shelf. The northern shelf has an average width of 58 km and mean seaward declivity of 1 m per kilometer (Gould and Stewart, 1955). The shelf margin occurs at an average depth of 55 m, and marks a transition to a slope which averages 4 m per kilometer to a depth of 183 meters (Gould and Stewart, 1955). The structure of the continental margin of the Gulf of Mexico is complex (Antoine et al., 1974), resulting from tectonic activity related to salt movement, reef growth, current activity, and the massive influx of sediment along its northern boundaries.

4.7 Review of Structure and Sedimentary Framework

Little is known of the pre-Mesozoic history of the Gulf of Mexico basin (Garrison and Martin, 1973). Meyerhoff (1967) hypothesized that it existed as early as the end of the Precambrian. Stratigraphic evidence reported by Meyerhoff (1967) and Wilhelm and Ewing (1972) indicated that marine conditions existed as early as the Pennsylvanian-Permiam time. Evaporite deposits, chiefly salt, were being precipitated in shallow basins around much of the Gulf margin by Early Jurassic time (Murray, 1966; Halbouty, 1967; Kirkland and Gerhard, 1971). Great thicknesses of salt were deposited before evaporite accumulation ceased in Middle or Late Jurassic. Neither the conditions of formation nor precise boundaries of salt basins have been established. Great changes took place in the character of the northern Gulf at the end of Mesozoic time (Garrison and Martin, 1973). An increase in sedimentation rates which accompanied the subsidence of the Gulf Coast geosyncline formed a vast clastic sediment wedge which began to fill the northern Gulf. During Tertiary time the coastal plain prograded steadily southward into the basin. Marine depositional sites shifted northeasterly, superimposing on the southeastward growing wedge of terrigenous sediments, as source

areas migrated eastward to the watersheds of the Mississippi River in Miocene time and later (Hardin, 1962). The northern shelf is a region of structural and lithologic transition at the juncture of western clastic and eastern carbonate deposition (Garrison and Martin, 1973). The present form of the continental margin in this region of the Gulf was attained when the outbuilding prism of terrigneous sediments from the northwest buried the old Cretaceous reef off northern Florida and intertongued with the later Cenozoic carbonate deposits of the west Florida platform.

Only one significant feature, the S-shaped DeSoto Canyon (Jordan, 1951) interrupts the smooth topography of the upper slope. Harbison (1968) attributed its origin and course to a combination of late Tertiary erosion, deposition, and structural control by diapiric features clustered in the vicinity. The landward and seaward extensions of the canyon exist as buried channels in the subbottom.

Though not proven by drilling, the diapiric features clustered in the vicinity of DeSoto Canyon are believed to be salt domes (Antoine et al., 1967; Harbison, 1967, 1968). Marsh (1967) suggested the possible occurrence of a buried salt layer in the Florida Panhandle, and many other diapirs and topographic prominences are believed to be related to salt piercement (Uchupi and Emery, 1968; Antoine and Gilmore, 1970). South and east of DeSoto Canyon diapiric features are unknown, so the domes west of the canyon on the northern shelf may represent either the eastern margin or a drastic thinning of the evaporites of the Gulf Coast salt basin. Antoine and Gilmore (1970) suggested that competent limestone beds composing the west Florida platform south of the canyon may have prevented vertical migration of the salt. One large anticlinal structure is found between Cape San Blas and DeSoto Canyon. Located about 80 km south of Valparaiso, the structure, about 30 km in diameter,

may be the result of an igneous intrusion similar to those present elsewhere in the Gulf coastal province (Antoine et al., 1967).

The sediments making up the northern shelf from Cape San Blas to Pensacola are generally thick-bedded and dip gently seaward. A well developed erosion surface separates 2-10 m of unconsolidated Holocene sands from the underlying older, partially consolidated to consolidated sediments. Serveral buried stream channels are present. The best developed are on profile 39, s.p. (shot points) 56-96 and 158-162. Beginning close to the shelf break near the 55 m isobath on profiles 35, 36 and 52 are well-developed foreset and topset beds presumably associated with deltaic sedimentation. These features are seen on profile 35 from s.p. 51-59; profile 36, s.p. 75-121; profile 38, s.p. 139-151; and profile 52, s.p. 321-347.

Two small areas of normal faulting are found off Panama City on profile 52, s.p. 454-560 and 562-565.

On the western side of DeSoto Canyon from Pensacola to Horn Island, a well developed erosion surface separates 2-8 m of unconsolidated Holocene sands and in the extreme western portion, silts and muds, from the older underlying partially consolidated to consolidated sediments. Several buried stream channels are present and best developed on profile 42, s.p. 98-107 and profile 50, s.p. 99-110 and 115-120. A sediment-filled depression which may be an extension of the Mobile Graben is found on profile 44, s.p. 99-120.

The entire shelf west of profile 42, s.p. 157 and profile 52, s.p. 192 is highly faulted and indicates extensive disturbance to the bedding. This is believed to be the result of diapiric intrusion.

Buried foreset and topset beds presumably associated with deltaic deposition are on the west side of DeSoto Canyon near the shelf break

on profile 41, s.p. 206-225; profile 42, s.p. 1-43; and profile 52, s.p. 192-223.

Well developed slump structures are present on profile 41, s.p. 215-255 and profile 42, s.p. 1-5; slump structures are also indicated on profile 52, s.p. 216-220.

Buried reefs and reef pinnacles are common around the margin of DeSoto Canyon. On the western slope these features are present on profile 41, s.p. 183-225; profile 42, s.p. 1-19 and 24-27; and profile 52, s.p. 183-225 and 226-233. On the eastern side, more extensively developed buried reefs are found on profile 34, s.p. 182-186 and 189-200; profile 35, s.p. 1-67; profile 36, s.p. 127-135; profile 37, s.p. 67-72 and 85-87; profile 38, s.p. 1-84 and 141-148; profile 40, s.p. 175-189, 227-231, 233-246 and 253-275; and profile 52, s.p. 257-266, 280-287, 295-302 and 311-321.

4.8 Carbonate Buildups

The only significant carbonate buildups are around the margin of DeSoto Canyon. According to Ludwick and Walton (1957) the reef pinnacles occur at either one or both depth zones - 68-84 m and 97-110 m. Between these zones the bottom is generally smooth. Most of the wider zones and higher pinnacles are found in the deeper zone. The deeper zone averages 2.2 km in width with pinnacle heights averaging 7 m in height. Exposed pinnacles are found on the following transects on the eastern side of the canyon: profile 34, s.p. 162-168, 171-172 and 178-183; profile 38, s.p. 200-204, 205-211, 212 and 224 and profile 52, s.p. 279-316. On the western side of the canyon they are found along profile 41, s.p. 203-205; profile 42, s.p. 5-30, 11-14, 29-31, 35 and 49-51; and profile 52, s.p. 202-204, 209 and 218-221.

## 4.9 Shallow Geologic Hazards

Three categories of possible geologic hazards exist.

Faults are very numerous in the area between Horn Island and Pensacola from near shore to the shelf break. Also, a few small faults exist on the shelf offshore from Panama City, extending from about mid-shelf to nearshore.

Unstable slopes exist around the upper slope in the vicinity of DeSoto Canyon. This condition is more common on the steeper western side where much slumping, especially to the south, is evident.

Geotechnical variability (i.e., zones of varying sediment size) is common on the shelves both east and west of DeSoto Canyon. This is best displayed in areas where fields of sandwaves are numerous. From the shelf edge landward sediment of varying size fills old drainage channels producing local anomalous substrate condition.

## 5.0 Texture Maps

### Introduction

Characterization of the surficial sediments of the MAFLA shelf was the primary objective in preparing the lithologic map. The geophysical reconnaissance survey conducted during August, 1975 was designed, in part, to efficiently collect data to supplement the existing box-coring program.

The unique value of side-scan sonar (SSS) data is its continuity as opposed to the serial nature of discreet sampling. Sedimentary patterns and morphologic elements at widely varying scales can be efficiently, although indirectly, observed. Other methods by which similar data can be obtained are direct visual contact, photography and closed circuit television (CCTV). The first two methods suffer in comparison with SSS on the basis of cost and time effectiveness and

were logistically not possible on the scale of this survey. However, the towing of an underwater CCTV sled would be a valuable aid in interpreting some of the more ambiguous sonar signatures that we encountered.

Traverses were made along the six predetermined benthic transects and were augmented with as many connecting profiles as possible within the imposed logistic constraints (Figures 1, 2 and 3). A total of 3700 km of profiles were completed shoreward of the 200 m isobath.

To characterize areas of high variability, side-scan sonar surveys are normally designed with a much higher transect density (as close to 100% converage as possible) and are then supplemented with samples or observations at critical or "type" areas. Thus, for optimal utility, the bottom sampling strategy should be dependent upon the sonar data and its design should obviously follow rather than precede acquisition of the geophysical profiles.

Ground truth is needed for determining bottom texture and for identification of enigmatic sonar signatures. Both may be accomplished simultaneously by towing an underwater CCTV sled. An underway sediment sampler would aid in the interpretation of the acoustic drag records.

More work is needed in several areas. Of particular interest are the pinnacle zones around DeSoto Canyon and on the outer west Florida shelf between 27°N and 28°N, the Florida Middle Ground reef complex and other undocumented "hard banks" and pinnacles associated with the shelf margin. Outcrops on the inner west Florida shelf, the irregular-hummocky area south of Mobile Bay and all active lease blocks should be subjected to additional geophysical documentation. Many areas of the MAFLA shelf need clarification of unknown targets some of which appear to indicate significant amounts of hard substrate in areas presently characterized as "soft" muddy bottom.

5.1 Data Reduction and Methodology

The principal elements depicted on the side-scan "texture" map are the relative reverberation level and "hard" bottom types.

Reverberation Level

McKinney and Anderson (1964) measured backscatter levels from a number of locations around the coast of the United States and presented these data as functions of frequency, grazing angle and bottom type (i.e., particulate nature and relief). At frequencies of 10 kHz (cf. 100 kHz used in this reconnaissance), backscattering increased with angle of incidence from about 5° up to the critical angle. Above the critical angle (about 10° for mud and 10° to 30° for sand and gravel), backscattering was "essentially" independent of the grazing angle. At angles of incidence between 10° to 20°, averaged data indicate significant differences in backscatter levels (approximately 20dB) between mud, sand and gravel bottoms, although a considerable range and overlap for each type of bottom was noted. Sand was the most variable with a range of about 5dB.

Wong and Chesterman (1968) noted that the scattering strength at low angles of incidence increased by nearly 25dB as the textural grade changed from clay through silt, sand and rock. The erratic distribution of backscattering coefficient noted in bottoms of the same sedimentary unit indicates that bottom roughness is also an important factor in the level of backscatter observed near grazing incidence. These investigators observed a "significant" positive correlation (0.9) between backscatter strength and the percentage of sand in the sediment. This suggests that particles of sand size or larger are the major scatterers at low angles of incidence.

Although grain-size parameters are easily measured on bottom samples,

the roughness factor cannot be fully accounted for in a reconnaissance survey. Forunately, the textural grade and roughness are commonly interdependent and some roughness information is avilable at least along the trackline, so the correlation of observed backscattered levels with textural parameters is possible (if not precisely at least qualitatively). With this objective in mind, the relative amplitude (or reverberation level) of the backscattered sonar signal is the principal parameter depicted on the side-scan sonar "texture" maps (Figures 26, 27 and 28). This level was estimated by visual comparison of the analog record to predetermined standard swatches of differing intensity, much as one uses color comparison charts to make field determinations of sediment color. Because of the qualitative nature of the data, only three ranges of intensity are designated - weak, moderate and strong backscatter (see Fig. 29b). All other factors being equal, these would roughly correspond to relatively fine, medium and coarse sediments, respectively. However, the reader should remain aware that other variables, such as particle shape and packing, angle of incidence, slant range and machine settings, can be a dominant factor in controlling apparent reflectivity. Some variation in the latter three factors can be accounted for by referring to shipboard log books during the interpretation.

Because the primary purpose of the texture map was to aid the projection of textural trends from a very low-density sample net, we will where appropriate, refer to weak, moderate and strong reverberation levels as relatively fine, medium and coarse bottom respectively. The latter units are dimensionless, except in a relative sense, and in some cases are of only local significance (i.e., <u>detailed</u> regional comparisons should be attempted with extreme caution). The terms fine, medium and coarse are also less cumbersome when comparing our results

to previous shelf studies (see Discussion and Conclusions).

Unfortunately, the three basic units of relative backscatter intensity cannot be mapped on much of the shelf due to the existence of patchy bottom (i.e., small-scale lateral variability). Patches much smaller than about 1000 m are considered unmappable at 1:250,000. Consequently, we could either map the variable areas according to the dominant texture, thereby neglecting subordinate texture(s), or we could attempt in some way to depict the nature of the variability. Our final format is a realistic compromise which incorporates both the variability (or uniformity in the case of the three basic units) and the dominant acoustic texture. This classification scheme is shown in Figure 29a, which defines twelve units that can be used to describe any texturally-dependent backscatter characteristic observed on the side-scan sonar profiles. These can be tabulated as follows:

| | |
|---|---|
| Fig. 29b | Three basic units: weak(W); moderate(M); strong(S) |
| Fig. 29c | Six 2-component classes (e.g., S>M, strong dominant over moderate) |
| Fig. 29d | Three 3-component classes (e.g., S>M,W strong dominant with some moderate and weak patches) |

In practice, however, visual estimation of dominance of one textural type in a variable situation becomes increasingly difficult as one approaches the transition to another class. In cases where no clear-cut decision could be made with regard to dominance, we added classes indicating that the components were observed in approximately equal proportions (see Figure 29c). This figure implies that dominance determination requires at least a 10% difference in relative proportions. This is, of course, only a very rough estimate as it is considerably easier to determine dominance for a S-W combination than a S-M or M-W. This modification results in the addition of three more classes for a total of fifteen.

The fifteen classes were plotted where observed on the appropriate segments of the geophysical profiles (Figures 26,27 and 28). From these, major trends could be determined and are described and discussed in later sections.

Hard Bottom Types

The other important elements in the acoustic "texture" map are the hard bottom types. These fall into two basic categories:

1) exposed low-relief hard substrate (outcrops)

2) "reefs" including a) major reefs (high relief)
b) linear coral-algal ridge trends
c) pinnacle "reefs"

With the exception of type 1, these usually present little difficulty to the interpreter. Detection of low-relief hard substrate, however, does pose some difficulty. All textural interpretations of side-scan sonar data routinely require augmenting subbottom profiler data. Where subbottom reflectors appear to outcrop or little or no penetration is achieved and the sonar data indicate a corresponding high reverberation level, a hard outcrop would seem to be the most reasonable interpretation. The difficulty, in many instances, is the determination of actual exposure. Because of limitations due to pulse width and ringing in shallower areas, sediment thicknesses of less than about 1 meter (especially in sand) are extremely difficult to detect. Some of these high reflectivity areas are probably very coarse sand or gravel lags, and, where bedforms are present, can be designated as such. Because of the ambiguities possible in attempting to differentiate very thin veneers of coarsematerial from lithified material, we decided to conservatively limit the areas mapped as outcrop to bottom that looked "rocky". That is, an area was classified as an exposed hard substrate only if it exhibited (1) surface roughness

(e.g., solution features, acoustic shadows due to relief, etc.) in addition to (2) high reverberation level and (3) seismic profiler evidence for an exposed strong reflector.

Recognizing the possibility that significant areas with outcrops migh be present where the unconsolidated sand veneer is very thin, the 5 msec sediment thickness contour was added to the reduced scale version of the texture map (Figure 30). Landward of this line less than 2-3 m of unconsolidated sediment overlies a lithified substrate and outcrops can be expected within segments mapped as coarse or having patches of coarse bottom.

5.2 Results - Peninsular Shelf[1]

The side-scan sonar (SSS) texture maps (areas covered by Figures 27 and 28) graphically illustrate the complexity of lithotopes present on the west Florida continental shelf. Seaward of the inner shelf break (average depth about 80 m) textural types occur in relatively large and uniform patches. Shoreward of this line variability increased in conjunction with a general decrease in size of mapped sub-divisions. Extreme variability was observed on transects shallower than 20 m along the west coast of peninsular Florida (i.e., transects 1,12,20 and 21).

For discussion purposes, we have subdivided the west Florida shelf into three major zones based on dominant acoustic character, degree of textural variability and presence or absence of various types of hard bottom (i.e., rock outcrops and "reefs"). These three zones roughly parallel the bathymetric trends (i.e., trend north-south) and are

---

(1) We have divided the study area along a line SW from Cape San Blas. The "peninsular shelf" lies south of this line and the "northern shelf" lies west of it.

designated on Figure 30 as Zones I through III from deepest to shallowest. In addition, the major zones were often noted to contain more subtle, but locally significant, subordinate trends which are designated by lower case letters.

As emphasized in the previous sections, although we are really mapping the relative amplitude (or reverberation level) of the backscattered sonar signal, we will often refer to the mapped divisions by their presumed textural equivalents. The sonar-texture maps are to be considered qualitative, (which is perhaps all one can expect from a reconnaissance level survey), as the lateral variations are sufficiently complicated on most of the shelf that projected trends must necessarily be generalized. One may note that the textural similarities on which Zones II and III are based are so general that they can include up to 12 of the 15 classes, and in fact, Zone III is designated partly on the basis that it includes significant areas locally dominated by all three basic units. The balance of this section consists of brief descriptions of the prominent characteristics and range of each Zone.

For the convenience of those who may not have access to or room to spread out the large 3.7 sq m maps represented by Figures 26, 27 and 28, we have condensed major features onto one smaller map which is included with the text as Figure 30. This map lacks the detail and control corridors that are plotted on the primary version, but is adequate for general reference and comparison to other published studies of the area.

As a visual aid to understanding the basis for the following subdivisions of the shelf based on the rather complex distribution of plotted data, a ternary diagram was constructed for each major and subordinate zone designated. All sonar data lying within a zone were tabulated on the basis of line mileage and from this, the proportion of

bottom within the zone attributable to each class was calculated (Figure 31). Five general levels of occurrence were designated as follows:

| | |
|---|---|
| 0-4% | - insignificant (except locally) |
| 5-10% | - significant occurrence |
| 11-20% | |
| 21-40% | - dominant occurrence |
| >40% | |

This analysis serves as a check on the zonation proposed in Figure 30. Although the zonation was based on more than the proportions of various kinds of unconsolidated sediment, it can be seen that the triangles in Figure 31 are sufficiently different from each other to confirm that the somewhat arbitrary subdivision is valid. In cases of similarity such as IIc vs IIIc, the distinction was originally based on at least one other factory (i.e., outcrops in IIIc).

The ternary diagrams in Figure 31 should be considered as an integral part of the side-scan "texture maps".

ZONE I - West Florida Outer Shelf and Upper Slope

Zone 1 is the deepest of the three major trends surveyed on the west Florida continental terrace and is characterized by a thin blanket of sediment exhibiting relatively low to moderate levels of backscatter. In contrast to the uniformity of Zone I west of Cape San Blas, our data indicates a region of broad transition with reflectivity and variability increasing landward. Consequently, we have subdivided the area into subzones I(a) and I(b) which may be characterized as follows:

Subzone I(a) is the deepest trend surveyed and is dominated (99% of area) by a uniform blanket of low reflectivity sediments. Small patches of sediment exhibiting slightly higher reverberation levels are associated with unidentified low relief targets that locally veneer the blanket,

especially south of 28°N (see <u>Unidentified Targets</u>). As far south as 26°45'N the eastern boundary with subzone I(b) usually occurs in depths of 130 to 170 m. At this latitude subzone I(a) extends east (landward) to about 100 m on geophysical profile 6 at the southern extreme of the area surveyed.

Considering the uniform acoustic character of these deposits, they should be well characterized by the four box core sites which were occupied within the area during the 1975 sampling program (station number 2106, 2212, 2313 and 2427).

Subzone I(b) is differentiated from I(a) primarily by the presence of large, mappable areas of moderate reflectivity sediments. Both subzones are characterized by uniform bottom indicative of blanket deposits which thin near the inner shelf break. The boundary of zone I (b) occurs just seaward of the shelf break on most transects. On sub-bottom profiles it is noted that this boundary often coincides with the landward pinch-out of an upper layer of low impedance sediments.

Subzone I(b) ranges in width from about 90 km on the central portion of the outer shelf to less than 10 km at the northern and southern extremities. South and west of Cape San Blas the character of the transition changes, becoming narrower and more variable in character, so I(b) is not mapped as a separate zone (see <u>Results - Northern Shelf</u>). The large salient of I(b) type bottom into Zone II, between 28° and 27°30'N, might have been mapped as a detached unit on the basis of sonar control. However, the apparent relationship of this zone to bathymetry suggests that it is probably a continuous extension blanketing the trough landward of the adjacent spur-like ridge.

The areas exhibiting moderate backscatter levels appear to result from two different phenomena. With increasing distance from the shelf

break south of 28°, we noted increasingly dense concentrations of unindentified targets which appear to be local accumulations of significant amounts of coarser skeletal debris. The most striking examples are the pinnacle "reefs" between 27° and 28°N (Figures 28 and 30). These skeletal buildups were observed in a belt-like trend extending at least 90 km north-south and up to 17 km in width between the 110 m and 180 m isobaths. Locally, the pinnacle concentrations vary from about 100 to 900 targets per square kilometer. Maximum relief is usually less than 5 m with a diameter: height ratio on the order of 10. The other shallower occurrences of sediment exhibiting moderate backscatter levels are probably related to exposures, or near exposures, of underlying higher impedance sediments and the coarser sediments of Zone II and are likely derivatives of these deposits.

In contrast to subzone I(a), which characteristically exhibits a minimal variety of subsurface structure, I(b) contains diverse types of buried constructural features.

The transition zone contains only two box core sites (2105 and 2426) which are located at the northern and southern extremities of the mapped area. The major pinnacle trend that we have noted was not included in the benthic sampling program.

ZONE II - West Florida Middle Shelf

Zone II is rather diverse and includes almost all mapping classes employed in this investigation, including both "acoustic-textural" and hard bottom types. Apart from its diversity, it is typified by bottom dominated by higher levels of backscatter than Zone I. It is also associated with almost all of the major coral-algal bank and reef trends that we have observed on the west Florida shelf. The boundary with Zone I is usually well defined near the shelf break, while the landward

boundary with Zone III is diffuse but approximates the 20 to 22 m isobaths between the Apalachicola barrier coast and Charlotte Harbor. Zones II and III are differentiated primarily on the basis of the common occurrence of scattered outcrops in Zone III as well as contrasting acoustic texture. To the northwest of the Apalachicola coast the acoustic texture of Zone II grades landward into the more diverse, but apparently finer terrigenous sediments of Zone IV (see Results - Northern Shelf).

Every box-core transect on the west Florida shelf in the BLM-MAFLA 1975 program sampled Zone II. These include stations 2103, 2104, 2208, 2209, 2210, 2211, 2314, 2315, 2316, 2317, 2421, 2422, 2423, 2424, 2425 and 2426, for a total of sixteen on four transects. However well this compares to the sampling of Zones I(a) and I(b), it is likely that ten times this sampling density would only just begin to define many of the diverse lithologic trends within Zone II.

Three subordinate textural trends are of sufficiently distinct character and areal extent to be separately designated (refer to Figure 31 for ternary diagrams). The largest and perhaps most prominent are the "strong dominated" subzones II(a) and II(b).

Subzone II(a) is a relatively narrow belt of bottom dominated by uniform strong and variably strong to moderate backscatter levels, best defined just landward of the shelf break between the 50 and 80 m isobaths. Included, and presumably intimately associated with this trend, are a series of discontinuous linear hard ridges with crests encountered most often at depths ranging between 55 and 75 m. A number of well developed pinnacles were also noted seaward of these ridges between 75 and 80 m. Usually the linear ridges were observed in pairs. Although most of Zone II is characterized by patchy (i.e., texturally

variable) bottom, both of the "coarse" dominated subzones contain relatively large areas mapped as uniform-strong. These uniform high reflectivity areas tend to occur on topographic highs associated with the linear spur-like ridges developed at about 50-60 m near the shelf break. No box-core samples were acquired from subzone II(a) during the 1975 program.

Subzone II(b) is the largest of the subordinate trends in areal extent. The western and southern portions of this trend also contain extensive areas of bottom characterized by uniform and strong backscatter levels. To the east and southeast this subzone is composed of increasingly more "strong dominated-weak" reflectivity bottom.

Four samples from benthic Transect IV were acquired from the northern part of II(b). These includes Stations 2425, 2424, 2423 and 2422. None were obtained from the south and southwestern portion of this trend.

The other subordinate trend, II(c), is not texturally characteristic of Zone II as it contains significant areas mapped as uniform-weak and variable-weak dominant with strong backscatter levels. However, in contrast to Zone III, no outcrops were mapped in II(c). The bottom type in this subzone becomes increasingly common south of 28°N inside the 40 m isobath. With additional control it is suspected that II(c) might persist further west between 26°30' and 28°N. On textural basis alone, this zone is similar to III(a), (c) and (d) type bottom (see Figure 31). Three box core stations (2103,2208 and 2209) were occupied in Subzone II(c).

Although described in more detail in the section on Carbonate Buildups, it should be noted that the Florida Middle Ground reef complex also lies within mapped boundaries of Zone II. These reefs are

the only example of high-relief (greater than 10 m) hard substrate that were detected in the MAFLA area. Without elaboration in this section, we note that south of what is classically mapped as the eastern ridge, is a dissected, hard, pinnacle-like, 30 km long extension having somewhat lower relief (see Figures 22, 9 and 8). Both the "main" eastern ridge and its southern extension are developed along the strike of a shallow subsurface limestone terrace (cf. 5 msec. isopleth, Figure 30) of probable late Teriary age. A major area of outcrop, encountered on profile 29 about 15 km. north of the Florida Middle Ground, also appears to be aligned along the same strike trend (Figure 5). These large areas of hard substrate, which are presumably important ecologically and commercially, have received little previous study and have not been sampled in the current program.

Examination of the subbottom profiles suggests that the sediments within Zone II range from blanket type deposits in portions of II(a) and II(b) to a thin, often discontinous veneer becoming increasing thin to the east and northeast. This veneer, landward of the 5 msec isopleth, is very discontinuous, with common exposures of either hard bottom or thin deposits of coarser lag overlying a karstified limestone surface. Shallow subbottom reflectors in areas seaward of the 5 msec isopach, especially near the shelf break, exhibit abrupt, local increases in impedance contrast suggesting lithification (probably biogenic). This, cannot be verified in the absence of velocity or core control.

ZONE III - West Florida Inner Shelf

While exhibiting less acoustic diversity overall than Zone II, Zone III is generally more patchy with respect to the size of mappable bottom types (cf. Figures 27, 28 and 31). The area is roughly bond by the 20 to 22 m isobaths between Cape San Blas and Charlotte Harbor and aside

from areas of weak backscatter, is principally characterized by exposures of low-relief hard substrate. Inshore, north of Tampa Bay, outcrops are more common and a discontinous veneer of low reflectivity sediments predominates. This area is designated as sub-zone III(a).

Although outcrops are probably common to much of the region within the 5 msec isopach (Figure 30) in both Zones II and III, the majority of the areas which we could confidently map as hard outcrop, employing the restrictive criteria outlined in the Data Reduction and Methodology section occur in III(a). Except for the area north of the Florida Middle Ground (see Zone II description), most of the mappable outcrops terminate seaward at about 20 to 22 m. Subtle terrace development between 20 and 30 m is indicated by a slight inflection in the regional slope on the Precision Depth Recorder (PDR) profiles which corresponds to the seaward terminus of the major outcrop trend.

Another important characteristic of side-scan records from Zone III, primarily in the "Big Bend" area, is a number of unusual acoustic signatures attributed to dense macro-epibenthic communities of unknown character. These occur in association with both hard and unconsolidated substrates, the acoustic character of the community differing in each case (see Unidentified Targets).

South of Subzone III(a), between Tampa Bay and Charlotte Harbor, the bottom generally exhibits high levels of backscatter and mappable outcrops become less common. This textural trend is shown on the ternary diagrams for subzones III(b) and III(c) in Figure 31. The "coarsest" bottom, and incidently the major occurrence of hard bottom noted south of Tampa Bay, was observed off the headland at Venice, Florida, along profile 1 (see corresponding ternary diagram for III(b)). At the southeastern extremity of Zone III, off Charlotte Harbor, the bottom type is classified as weak to moderate and is designated as subzone III(c).

In general, Zone III sediments are very patchy, the lower reflectivity bottom being associated with long wavelength, low relief swells (see Bedform Maps) and filled depressions. Areas characterized by higher reverberation levels were most often associated with troughs, perhaps indicating scour or thin residual coarse lag deposits and/or hard substrate. Zone III sediments exist as a discontinuous veneer overlying a hard limestone substrate and are generally less than a few meters thick, except as valley, doline and channel fills.

Four box core stations (2207, 2318, 2420 and 2421) were occupied in subzone III(c); two in III(d), (Stations 2101 and 2102); one in III(a), (Station 2419); and none in III(b). It should be noted that surficial deposits of subzones II(c) and III(c) are acoustically similar. The zone differentiation being based on the occurrence of outcrops.

5.3 Results - Northern Shelf

The side-scan sonar texture maps (areas covered by Figures 26 and 27) illustrate that the northern shelf lithotopes are less complex than those on the peninsular shelf.

For discussion purposes the northern shelf has been divided into three major zones based on dominant acoustic character, degree of textural variability, and presence or absence of hard bottom (i.e., "reef"). These zones are designated on Figure 30 as Zone I, IV and V.

Zone I (Figure 30), the northern extremity of DeSoto Canyon, is the deepest of the three major trends surveyed on the northern shelf, and is characterized by a blanket of sediment exhibiting relatively low to moderate levels backscatter. The eastern boundary within subzones IV(e), (f) and (g) usually occurs between the 60 m and 100 m isobaths, but is near 130 m on geophysical profile 38. The western boundary within subzone IV(d) occurs between the 100 m isobath to the north and the 300 m isobath to the south.

Considering the uniform acoustic character of this deposit, it should be well characterized by box core stations 2535 and 2536 near geophysical profile 36. The box cores were composed of an average of 22 percent sand, 66 percent silt and 11.5 percent clay with a total sample carbonate content of 71.7 percent. Ludwick (1964) collected 94 samples on a transect approximately 10 km. west of the box core sites. Analyses of the sediments were grouped into two modal mixtures, one of which agreed well with the box cores and contained 26 percent sand (of which 21 percent was calcareous) and 75 percent silt and clay. Ludwick (1964) classified the easternmost part of Zone I as western Florida line-mud facies composed of a sediment with an average median grain-diameter of 0.050 mm., sorting coefficient of 2.68 (Trask), all grains less than 2 mm., quartz grain size of 0.5 mm., 80 percent carbonate, 10 percent quartz, 7 percent clay minerals and 3 percent glauconite. The carbonate is made up of 25 percent foraminifera and 55 percent fragmental debris, while the glauconite is almost exclusively casts of foraminifera.

No box cores were collected in the western portion and no studies of the sediment have been published except that of Ludwick (1964). He classified this as an area of upper continental slope clays which agrees with the uniform backscatter level in this zone.

Zone IV (Figure 30), includes most of the northeastern Gulf of Mexico shelf shoreward of Zone I from Cape San Blas (where it grades into subzone II(b)) to Dauphin Island, where it merges with subzone IV(a). This is a rather diverse zone and includes all mapping classes employed in this investigation including both "acoustic-textural" and hard bottom types. Apart from its diversity, it is typified by a bottom dominated by higher levels of backscatter than the other zones on the MAFLA shelf. It is also associated with all the major reef trends observed around the margin of

DeSoto Canyon. The boundary with Zone I is well defined, and was as described in Zone I. The boundary with subzone V(b) is well defined near the 32 m isobath, while the boundary with subzone V(b) is well defined near the 32 m isobath. The contact with II(b) off Cape San Blas is gradational and approximately perpendicular to the shoreline. Although this zone is characterized by variable backscatter levels, sufficient differences exist to warrant subdividing it into subzones IV(a)-IV(g).

Subzones IV(a)-IV(d), located on the MAFLA shelf between Navarre Beach and Mobile Bay (Figure 30), are in the Mississippi-Alabama sand facies described by Ludwick (1964). He reported the modal composition of the sediment as 93 percent terrigenous sand, 7 percent silt and clay, median grain size 0.180 mm., sorting coefficient of 1.26 (Trask), no grains coarser than 2 mm., and the coarsest quartz grains 1.3 mm. in diameter.

Upshaw, Creath and Brooks (1966) described these sediments as generally fine sands seaward of the barrier island chain, with the exception of an elongate mud deposit immediately seaward of Dauphin Island. Open Gulf sediments, except for local interruptions, exhibit prominent size gradients. From the open shelf east of Mobile Bay coarse and medium sands grade westward into fine and very fine sands and then into silts and claymuds. From north to south across the continental shelf margin, the same trend, though more abrupt, is apparent.

Subzone IV(a) (Figure 30), south of Mobile Bay is bounded on the west by Zone V. To the north along geophysical profile 44 the boundary is diffuse while to the south along profile 47 it is distinct. To the south and east the contact with subzone IV(b) is diffuse and somewhat arbitrary. Variable backscatter levels are predominately moderate

dominant over low. No box core stations were occupied in this area. Upshaw, Creath and Brooks (1966) report that this portion of the shelf is predominantly fine sand with a small area of very fine sand in the southwest corner and a somewhat larger area of medium sand to the northeast. The sediment is generally composed of more than 75 percent quartz, less than 10 percent silt and clay and less than 10 percent carbonate. Much of the variability shown by sonar apparently results from the gradation into the St. Bernard prodelta deposit to the west and into the silt and clay from the Pascagoula River and Mobile Bay to the north. Though most of the bottom is relatively smooth, a few sandwaves and other irregularities probably contribute to the irregular sorting and distribution of sediments.

Subzone IV(b) (Figure 30), south and east of subzone IV(a) is bounded on the west by subzones IV(a) and V(b), to the north by IV(a) and east by IV(c). Backscatter levels were more highly variable than in subzone IV(a) with moderate dominant over strong. Two box core stations (2639 and 2640) were occupied near the beginning and end of geophysical profile 48. Station 2639 was 85.6 percent sand, 8.2 percent silt and clay, reflecting its nearness to subzone V(b). Station 2640 was 98.2 percent sand, 1.7 percent silt and clay, with a total sample carbonate content of 19.7 percent. Results of the study by Upshaw, Creath and Brooks (1966) show subzone IV(b) to be predominately fine sand, with very fine sand in the southwest corner and medium sand in both the northeast and southeast corners. Quartz made up from 50 to more than 75 percent of the sediment, silt and clay less than 20 percent with up to 20 percent carbonate. The high degree of backscatter variability is due both to the irregular nature of the bottom, as well as to the irregular grain size distribution. Sediment sorting and distribution by wave and current action is impeded by the irregular bottom topography.

Subzone IV(c), a linear zone widening from 24 km in the south to about 60 km to the north, is bounded on the west by subzone IV(b) and on the east by subzone IV(d). Backscatter levels and variability were similar to subzone IV(a) with moderate dominant over weak. The one box core station (2641) near the beginning of geophysical line 50, was made up to 95.8 percent sand, 4.1 percent silt and clay and a carbonate content of 5.3 percent. Basically this subzone differs from IV(a) in that the latter contains less sand and more silt and clay. Fine sand is the dominant sediment is IV(c) with an area of medium sand in the northwestern corner and southern one-third, according to Upshaw, Creath and Brooks (1966) who also reported that quartz made up over 75 percent, silt and clay up to 10 percent and carbonate up to 20 percent of the sediment. As in IV(b) the variability is in large part a result of both irregular sorting and distribution of sediments as well as a very irregular bottom topography.

Subzone IV(d), a linear zone narrowing from about 40 km to the south to about 5 km to the north (Figure 30), is bounded on the west by subzone IV(c) and on the east by Zone I. Backscatter level variability decreases from south to north, resulting partly from the bottom topography grading from irregular-hummocky to low-relief swells in the south to a flat smooth bottom in the north. Four box core stations (2642, 2643, 2644 and 2645) were located near geophysical profile 42 in the southern end of this area. Station 2642 near the boundary with IV(c) contained 98.2 percent quartz, 1.7 percent silt and clay, and a total sample carbonate content of 6.5 percent. Stations 2643 and 2644 were composed of an average of 95.5 percent sand, 4.5 percent silt and clay and a total sample carbonate content of 86.2 percent. Much of the backscatter level variability is due to sediments in the reef and pinnacle areas. This zone includes Ludwick's (1964)

Mississippi-Alabama reef and inter-reef facies, a zone of high degree of variability. The reef phase has a composition of about 20 percent terrigenous sand, 70 percent carbonate sand and 10 percent silt and clay. This sediment has a median grain diameter of 0.710 mm, sorting coefficient of 2.14 (Trask), 19 percent coarser than 2 mm, and no large quartz or rock grains. The inter-reef sediments have a median-grain diameter of 0.120 mm, sorting coefficient of 2.47 (Trask), 4 percent coarser than 2 mm, coarsest quartzite grain 1.9 mm and largest single crystalline rock grain of 7.4 mm (Ludwick, 1964). Station 2645 was near the boundary of Zone I and had a composition of 88.5 percent sand, 6.6 percent silt, 4.8 percent clay and a total carbonate content of 84.3 percent.

Subzones IV(e) and IV(f) are in the Cape San Blas sand facies. Ludwick (1964) gives a modal composition of 90 percent terrigenous sand, 10 percent carbonate sand, and zero percent silt and clay. The average sorting coefficient is 1.22 (Trask). Three major sand types make up this facies: (1) fine-grained, well-sorted sand; (2) medium-grained, moderately well-sorted quartz sand containing some grains 1 to 2 mm in diameter; (3) coarse-grained quartz sand containing up to 25 percent grains coarser than 1 mm, and some grains 1.5 to 2.5 mm to diameter. The Cape San Blas and Mississippi-Alabama sand facies are thought to be isochronous, but are treated as separate facies due to differences in aspect. The position and nature of the contact between them is not known, but based on geophysical profile 52, the contact is probably gradational in nature and is located south of Navarre Beach, Florida.

Subzone IV(e), (Figure 30), located south of Destin, Florida, is bounded on the south by Zone I and subzone IV(g) and on the east by subzone IV(c). No box core sites were located in this area. Side-scan sonar records show backscatter levels varying mostly between moderate and weak,

indicating that sediments are probably medium sands with a smaller amount of finer sands. The coarser sands generally occur on the crests of the sandwaves with finer ones in the troughs. McLeroy (1972) describes this area as being mostly sand, but gives no sedimentary parameters.

Subzone IV(f), (Figure 30), between Panama City and Cape San Blas is bounded on the west by subzones IV(e) and (g), to the southwest by Zone I and to the southeast by subzone II(b). Backscatter levels of moderate dominant over strong indicate medium sand is most abundant, although much coarse sand is present. McLeroy (1972) shows this area as predominately sand and gravel with the silt content increasing seaward. Much of the backscatter variability apparently results from the large sand wave field off Cape San Blas from which sonar data and diver observations (T. S. Hopkins, Univeristy of Alabama, Pers. Comm.) suggest that coarser sediment is generally on the crests and finer sediment in the troughs. Five box core stations (2528-2532) in this area show an average of 95.9 percent sand, 3.9 percent silt and clay and 73.1 percent carbonate.

Subzone IV(g), (Figure 30), is an area of moderately variable sediments bounded on the west by Zone I and on the east by subzones IV(e) and (f). Box core stations 2533 and 2534 along geophysical profile 36 in this area have an average of 96.1 percent sand, 3.6 percent silt and clay and 87.9 percent carbonate, which agrees with the results of McLeroy (1972). This subzone includes the easternmost extension of the western Florida lime-mud facies and part of the transition zone into the Cape San Blas sand facies.

Zone V (Figure 30), an area of predominantly weak backscatter levels, extends from near the west end of Dauphin Island, Alabama, westward and seaward to just beyond the 30 m isobath. This zone coincides with Ludwick's (1964) Mississippi-Alabama barrier island sand deposit, sound and

bay deposit, and Mississippi-Alabama sand facies to the north and St. Bernard prodelta deposit and transition zone to the south. This zone can be further subdivided into subzones V(a) and V(b).

Subzone V(a), (Figure 30), south of Horn and Petit Bois Islands, Mississippi and the western end of Dauphin Island, Alabama, is bounded on the east by subzone IV(a) and on the south by V(b). Side-scan sonar records show this to be an area of variable weak to moderate backscatter levels. This variability results in large part from the irregular contact between the barrier island sand deposit, sound and bay deposit silts and clays, and the Mississippi-Alabama sand facies. Sonar records suggest that silts and clays are dominant with lesser amounts of fine to coarse sand being present. Ludwick (1964) decribes sound and bay muds as having a median grain-diameter of 0.002 mm, sorting coefficient of 6.56 (Trask), modal mixture of 5 percent terrigenous sand, 95 percent silt and clay, and no calcium carbonate. He describes the Mississippi-Alabama barrier island sand deposit as wholly terrigenous, coarsest diameter grains average 2.0 mm with a maximum of 7.0 mm, and sorting coefficient of 1.24 (Trask). The Mississippi-Alabama sand facies has beendescribed previously under Zone IV.

Subzone V(b), (Figure 30), lies west of IV(b). This entire area is characterized by uniformly weak backscatter levels, suggesting fine sediments. Ludwick's (1964) St. Bernard prodelta deposit coincides with V(b). He describes it as a homogeneous deposit having a modal mixture of 1 percent terrigenous sand, 4 percent carbonate sand, 33 percent silt and 62 percent clay. The median grain-diameter is 0.0015 mm with a sorting coefficient of 4.46 (Trask).

5.4 Discussion and Conclusions - Peninsular Shelf (Zones I, II and III)

At this stage, the significance of the descriptive data plotted on Figures 27 and 28 and summarized in Figures 30 and 31 can only be roughly assessed by comparisons to "ground-truth". Precise comparison of backscatter data with specific measurable bottom characteristics, such as textural grade, is precluded by the empirical nature of the backscatter estimates, the multiplicity of variables probably involved in the observed reverberation levels, and the improbability of accurately determining where the MAFLA program box-cores or previous samples were obtained relative to a specific point on the sonar records. The geophysical descriptions of certain middle and inner shelf core sites (see Station Atlas) indicate great variability and suggest the difficulty and uncertainty involved in characterizing even small areas by a few box-cores, much less attempting to project such information on a regional basis. Comparison of point data to sonar records in extremely variable localities requires knowledge of the exact core site within a few meters. This is possible, but because the current program employed two different navigation services [(1)] (Decca Hi-Fix and LORAC) and two separate cruises, it was not a very realistic approach in this case. Under the circumstances, the only valid comparisons between core sampling data and sonar control are from areas we found to have uniform bottom. Unfortunately, on the peninsular shelf only six of 27 coring localities were coincident with uniform

---

(1) Decca Hi-Fix was used for the geophysical cruise. LORAC was used for the first benthic sampling cruise which was closest in time to the geophysical cruise and to which we have attempted correlations. Later benthic sampling cruises employed Decca Hi-Fix.

bottom, and of these, four occurred in areas characterized by weak backscattering.

Table I shows that there is a definite increase in the sediment grain size from areas of weak to strong backscatter. However, the large range for uniform-weak areas, even in the average, should be taken as a cautionary sign.

Table I. Relationship between the acoustic-textural bottom type and the surface sediments graphic mean diameter.

| Acoustic-Textural Bottom Type | Number of Observations | Surface Sediments-Graphic Mean Diameter (Avg. from 3 Sampling Periods) |
|---|---|---|
| Uniform-weak | 4 | 0.14 mm avg. (range 0.01-0.26 mm) |
| Uniform-moderate | 1 | 0.41 mm |
| Uniform-strong | 1 | 0.62 mm |

Correlation of acoustic-texture to textural grade determinations from box-core samples is also complicated by the possibility of seasonal variations. For instance, box core station 2103 exhibited significant differences both within and between sampling periods I and II. Table II summarizes data from surface samples in two replicates for each season.

Table II. The effect of seasonal variations on the correlations between acoustic-texture to textural grade at box core station 2103.

| Size | | Period I Cumulative % | | Period II Cumulative % | |
|---|---|---|---|---|---|
| mm | phi | 2103A | 2103K | 2103A | 2103K |
| 2 | <-1 | 1.6 | 28.2 | 0.3 | 0.0 |
| 2-1 | -1-0 | 8.4 | 32.9 | 0.7 | 0.1 |
| 1-0.5 | 0-1 | 33.3 | 46.7 | 3.0 | 0.7 |
| 0.5-0.25 | 1-2 | 75.8 | 79.6 | 51.6 | 21.6 |
| 0.25-0.125 | 2-3 | 95.4 | 95.1 | 83.6 | 68.9 |
| 0.125-0.063 | 3-4 | 96.0 | 95.7 | 88.7 | 75.3 |
| 0.063 | >4 | 99.7 | 99.9 | 100.0 | 100.0 |
| Median Grain Size (phi) | | 1.4 | 1.1 | 2.0<br>2.0 | 2.7 |

The geophysical description of Station 2103 (see Station Atlas) indicates variable bottom. Thin lenses (1 m or less) of linear sediment overlie coarser material which is commonly exposed in intervening lows. The linearity and abruptness of the boundary between contrasting acoustic textures suggests three possible explanations for the textural differences between periods I and II;

(1) Samples were acquired from different localities (During a given sampling period this may simply result from vessel movements about the anchor line).

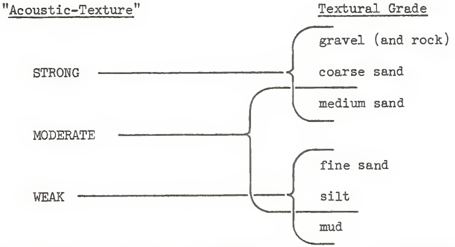
(2) The thin lens of fine sediment shifted or was removed during the time span between samples.

(3) The box-core penetrated a thinner section of the layer of fine surface sediments. The resulting mixture resulted in the observed change. In this instance, the first possibility is the preferred interpretation based on (1) textural data (samples distinctly different), (2) geophysical data (texturally variable bottom) and (3) navigation (two different navigation services employed). The second possibility is not a likely explanation of differences between replicate cores. The possibility of seasonal changes was not precluded as an explanation of between sampling variability and side-scan sonar data do indicate that the fine sand lenses may be mobile. Obviously, seasonal effects cannot be separated from navigational errors or vessel motion in areas of variable bottom.

To reiterate, the observed backscatter can be expected to vary, even with rather minor changes in textural grade and evidence for this phenomenon was reviewed by McKinney and Anderson (1964) and Wong and Chesterman (1968). Investigations by McKinney and Anderson (1964, employing frequencies comparable to those in this survey (100 kHz) showed an average increase in backscatter strength of 20dB from mud to gravel at angles of incidence

between 10° and 20°. The greatest contrasts were between mud vs. silt and sand and silt vs. gravel. Sand exhibited the largest range in values (about 5dB) for any one textural grade, overlapping the full range of silt and commonly equalling values noted for gravel and rock bottoms. Comparing their 20dB range to the designated print range (26dB, from lightest to darkest) of the recorder employed in this survey, it would seem that, at least in theory, an ideal combination of control settings would allow differentiation amoung the full range of textural types from mud to rock at a single locality. For a succinct discussion of why this usually is not practical, B.W. Flemming's excellent paper, "Side-Scan Sonar: A Practical Guide", is recommended (Flemming, 1976).

Without further elaboration at this point, comparison of our acoustic-textural classes to previously published regional studies on the west Florida shelf (Gould and Stewart, 1955; Ludwick, 1964) suggest the following general correlations:




Although the overlap is considerable, this is of consequence only on a regional basis. Data from a specific locality can be interpreted with more precision, given adequate control. For regional interpretations, details must be considered subordinate to gross generalities and the colors designating various bottom types on the Acoustic-Texture Maps

(Figures 26, 27 and 28) were chosen to aid visual integration of the detailed information presented. Blues, greens and yellows were chosen to represent the strong, moderate and weak dominated bottom classes respectively with the shades indicating the existence of associated "coarser" or "finer" subordinate class(es) in variable areas.

The only published investigation of the west Florida shelf sufficiently detailed to allow delineation of textural and lithofacies trends on a regional scale is Gould and Stewart's (1955) paper. Results from approximately 2,500 spot samples were summarized on three maps showing trends of sediment type and grain size distribution, these are included here on Figures 32a, b and c. On the basis of textural grade, they divided the shelf between 26°0' and 28°30'N into four broad zones according to the following scheme:

| | |
|---|---|
| inner shelf zone | - medium to fine sand (with significant areas or medium-coarse sand nearshore) |
| middle shelf | - coarse to medium sand |
| shelf edge | - medium to fine sand |
| slope | - medium to fine sand and silt |

The variable nature of the shelf sediments is probably responsible for their overlapping zone designations (i.e., all four are characterized by "medium" sand) as well as the number of "bullseye" facies boundaries on their maps (see Figure 32a). Despite these shortcomings, comparison of our acoustic-texture map to their grains size distribution map shows reasonably close correspondence if one accepts our proposed relationships of acoustic-texture to textural grade. Figure 33 is a diagrammatic correlation chart constructed to help clarify the relationships between our acoustic-texture trends and Gould and Stewart's trends. Table III summarizes most of the major correlations which can be made between the two data bases.

Table III. Comparison and correlation of acoustic-texture to compositional and textural trends established by Gould and Stewart (1955).

| This Study Acoustic-Texture Zone (Figure 30) | Gould and Stewart (1955) Grain-Size(Fig.32a) | Lithofacies (Figs. 32b and c) |
|---|---|---|
| I(a) and seaward portions of I(b); uniform weak and uniform weak to moderate. | Medium-fine sand and silt | foraminifera sand and silt |
| I(b) landward portion; uniform moderate to weak. | Medium-fine sand | north: foraminifera and algal sand and silt; south:oolite sand |
| II; variable strong dominant (excluding II(c)). | Coarse-medium sand | algal sand and seaward portion of shell sand |
| II(a), II(b)sw; variable to uniform strong. | Coarse-medium sand | algal sand belt |
| III including II(c); variable weak dominant | Medium-fine sand with significant areas of coarse-medium sand | quartz/shell sand shell/quartz sand and inner shell sand |
| III(a), III(c); variable weak dominant | Medium-fine sand | quartz/shell sand |
| III(b); variable mod. to strong dominant | Coarse-medium sand | shell/quartz sand |

An example of a major discrepancy between the zones designated on Figure 30 and the grain size distribution trends of Gould and Stewart on Figure 32a, is the tongue of coarse-medium sand which extends shoreward in the vicinity of Tampa Bay. If one considers that our boundary in this area was based on only one profile (13) and that the variability noted on this profile relative to Gould and Stewart's sampling density, the discrepancy becomes more acceptable.

The correlations between backscatter levels and lithofacies summarized on Table III and on Figure 33 might be a little surprising unless one accepts as fact the observation that textural grade is primarily a function of the composition of the sediments rather than physical processes related to depth of occurrence (Gould and Stewart, 1955). The composition of the sediments also controls other physical properties (i.e., roughness) that would affect the acoustic character of the bottom (Wong and Chesterman, 1968; McKinney and Anderson, 1964).

The objective in comparing our acoustic-textural trends to established textural trends is more an exercise in validating the interpretations rather than a re-evaluation of the state of knowledge of sediment distribution in areas already studied. From such a vantage one can more confidently assess the significance of the sonar data in areas where little control exists, such as the Big Bend region between Tampa Bay and Apalachicola. This portion of the west Florida shelf has not been subjected to any investigations as intense as the area to the south, and as a consequence any supplementary data would be of interest.

Our data show the following acoustic-textural trends on the Big Bend shelf between 28°30'N and 30°N.

| | | |
|---|---|---|
| Inner Shelf | - | variable-weak dominant; Zone III(a) |
| Transition | - | mixed weak to strong dominant; Zones III and II |
| Middle Shelf to shelf edge | - | uniform strong to variable strong dominant; Zone III(b) |

The inner shelf trend is probably an extension of the quartz dominated-fine sands which are observed along the central Florida barrier coast to the south. The transition from contrasting weak to strong dominated bottom may be indicative of fine sand lenses overlying exposed patches of hard bottom of coarse sediment (perhaps thin gravel lags). From the middle shelf seaward

to the shelf edge, backscatter levels become more consistently strong-dominant, commonly uniform-strong (cf. ternary diagram for III(b) - Figure 31). This shelf edge trend of strong-dominant bottom encompasses two contrasting lithotypes, coarse-shell and algal calcarenities in the southwestern portion of Zone III(b) and, what appear to be coarser terrigenous sands blanketing the northern and northwestern portions of the same zone. The latter interpretation is based on evidence from the box-core program, a few reconnaissance transects discussed by Gould and Stewart (1955) and a trans-shelf sampling profile in Ludwick (1964; transect 11). The terrigenous clastics shoreward and to the west (Zone IV) exhibited lower backscatter levels with the finer sediments often being associated with giant bedforms suggesting that periodic intense hydrodynamic activity may control their distribution (at least landward of 20 m; see <u>Bedform Maps</u>). The "coarser" sediments were found nearer the shelf edge and in troughs between large sand ridges and are commonly associated with exposures of a high impedence subbottom reflector noted on most of the profiles from this portion of the shelf. This reflector may be the down-dip equivalent of the basal transgressive coarse to "gravelly" quartz sands of the upper Pleistocene sequence (mid-Wisconsin?) noted in borings from Cape San Blas and St. George Island (Schnable and Goodell, 1968). In contrast, the terrigenous clastics of the Big Bend coast are apparently finer and are usually associated with thin (less than 2-3 m thick), discontinuous sediment swells and filled depressions.

Interpretation of various hard-bottom signatures from the side-scan sonar data is less ambiguous, with the exception of low relief types not exhibiting distinctive surface morphology (see <u>Data Reduction-Methodology</u>). There are two basic types of hard bottom frequently encountered on the west Florida shelf: (1) low relief limestone outcrops and (2) lithified

skeletal accumulations, including coral-algal banks/ridges and pinnacles. The majority of the first type identified was, by definition, characteristically associated with Zone III. Outcrops were most common north of Tampa Bay at depths shallower than 22 m and apparently extend northward of the vicinity of Dog Island at the western terminus of the Apalachicola barrier coast (Vause, 1959). South of Tampa Bay the only major occurrence was seaward of the headland at Venice. Flanking the latter occurrence, subbottom profiles were characterized by complex "cut and fill" structures, inclined bedding and recognizable filled valleys thought to be characteristic of filled embayments and paleofluves (see Structure and Physiography). The only other notable occurrence of outcrops was observed north of the Florida Middle Ground reefs, on profile 29, and they appear to be exposures of the limestone platform on which the eastern reef ridge system is developed. No other outcrops were designated on Figures 27 and 28, although much of the bottom characterized by strong reverberation levels landward of the 5 msec isopach of Figure 30 may be outcrop.

The maximum depth of outcrops observed in this study (40 m) is similar to the maximum depth of lithoclasts referred to by Gould and Stewart as "type 1 through 4 limestone fragments" (50 m). This and other comparisons of distribution trends are diagrammatically shown in Figure 33 and they include:

| | | |
|---|---|---|
| | 1) Patch reefs | - only observed on profile 21 at about 10 m. |
| "reef" types | 2) Coral-algal banks and ridges | - Common between 40 and 75 m, include the Florida Middle Ground complex and linear ridge systems at the shelf break. |
| | 3) Pinnacles | - Consistently occur at depth ranges 50-60 m, 75-90 m, 110-160 m; morphologically similar features associated with southeastern Florida Middle Ground reefs at depths of 31 to 33 m. |

| | | |
|---|---|---|
| Non-reef types | 4) Low relief "hard" targets see (Unidentified Targets - Types 2&3) | - Very common on the outer shelf and upper slope south of 28°N, although present on most of the deeper transects south of Cape San Blas. |

The shallow patch reefs (1) occur within the distribution range of living hermatypic corals noted by Gould and Stewart who also stated that such corals were only found as small patches and mounds of less than a few feet relief. Gould and Stewart suggested that patch reef occurrence was controlled by the existence of hard substrate. Brooks (1973) noted that small hermatypic patch reefs were found at shallow depths along the west coast of peninsular Florida as far north as Bayport, which is approximately where this investigation detected the patch reef signatures on profiles 21. North of Bayport, lower winter water temperatures are thought to preclude development and hermatypic corals as the principal hard bottom biotope (Brooks, op. cit.). The intimate relationship between shallow water coral and sponge reef development and hard substrate may be a reason the majority of outcrops were identified landward of the 22 m isobath. These communities probably contributed to the "ruggedness" factor employed in identification of hard bottom, the often stated maximum "ideal" depth range for proliferation being coincident. It should also be noted that the outcrops on the two northern profiles (24 and 25) on the Big Bend shelf exhibited a less rugged character and this may be attributable to lithologic differences (i.e., sandy limestones, less susceptable to karstification).

The major coral-algal bank and ridge (2) trends were observed only on the seaward portions of the middle shelf (these are discussed in more detail in <u>Carbonate Buildups</u>). The main trends are characteristically composed of two or more ridges which occur with enough consistency to suggest some continuity with the major gaps in continuity being noted between 27°N and 28°30'N. The linear nature is also verified by the

sonar records - all surface exposures extending at least the width of the record (about 250 mm). The ridge systems have been projected utilizing both historical control (Uniboom seismic profiles) and bathymetry. Continuous "scarps" on the latter between 50 and 80 m appear to be reliable indicators of the existence of hard ridges. Where multiple ridges were observed, the seaward ones were often buried under a thin blanket of more recent sediments. Some of the ridges had a flat truncated crest possibly indicative of a period of emergence. Subsequent arrestment of growth is difficult to explain.

Between the major north and south trends, linear ridges are discontinuous, extending only about 20 to 30 km. These are also associated with breaks in slope or are developed on morphologic highs. The best developed ridge was observed along the seaward margin of the large spur defined by the 60 m isobath just south of 28°N ("The Elbow"). North of the Elbow, the gap in ridge development may be related to the ridge and swale topography between 60 and 80 m southwest of the Florida Middle Ground on NOS bathymetric chart NH 16-12. Our Uniboom profiles crossing this area indicate that these morphologic features are of hydrodynamic origin and that the upper sand unit is considerably thicker than equivalent strata to the north and south. One can speculate that the area was characterized by shifting sand shoals during previous regressions and that mobile sediments limited reef development. Up-dip from the ridge and swale topography located between 28°20' and 29°N, was characterized by a number of hard banks with the most well developed being the Florida Middle Ground complex (detailed in Carbonate Buildups). What has apparently gone unnoticed, or at least unmentioned in previous investigations, were the smaller banks at depths of 40 and 60 m west and northwest of the Florida Middle Ground reefs. Where these were crossed with side-scan sonar, a hard bottom

signature was very apparent on the crests (see profiles 30 and 23, Figure 27). We suspect that a number of the other similar prominences shown on NH 16-12 are of similar character.

The primary structure of all type 2 coral-algal ridges resulted from the accumulation of skeletal material from a faunal assemblage characteristic of ecological conditions which existed during regressive stages of the late Pleistocene. The shallower exposed hard ridges are probably characterized by a living invertebrate assemblage indigenous to the present environment, and as such would be important links in the food chain controlling the distribution of valuable commercial and sport bottom fisheries (e.g., grouper and snapper banks).

Type 3, pinnacle reefs, are interesting because of their unique morphology which has been only rarely noted in the literature and most observations are from the northeastern Gulf of Mexico (Ludwick, 1964; Ludwick and Walton, 1957; Jordan and Stewart, 1959; also see a comprehensive review of prominences in the Gulf of Mexico by Poag and Sweet, 1975). The large belt-like pinnacle trend observed between 28° and 27°N in Zone I(b) is the northern most of two "patch reef" zones noted by Jordan and Stewart; the other lies outside the MAFLA study area. Ludwick and Walton (1957) dredged rocks from similar "belts of calcareous reef-like prominences" bordering DeSoto Canyon at slightly shallower depths (see Carbonate Buildups). These rocks were primarily composed of calcareous algae (dead assemblage) and the associated sediments were characterized by _Amphistegina_ and calcareous algal fragments. It seems reasonable to assume, lacking evidence to the contrary, that the major zone observed at greater depths on the outer west Florida shelf is of similar composition. The only rock samples acquired from the area are the foraminiferal limestone fragments mentioned by Gould and Stewart

(1955). These were dredged from 98 fm (180 m) and were also characterized by an Amphistegina assemblage. Since no mention was made of any associated algal material, these pinnacles may have a different genesis than those adjacent to DeSoto Canyon. The deeper pinnacles on the west Florida shelf also differ in that their development is not always associated with positive morphological elements and they do not appear to have developed on a hard substrate. In fact, our subbottom profiles suggest that their development began on a low impedance (fine sediment) substrate (medium-fine sand and silt zone of Gould and Stewart - our acoustic-textural zone I(b)).

Pinnacles are also common at depths of 75 and 90 m, slightly seaward of the linear coral-algal ridges characteristic of the shelf break. These prominences do not appear to occur in as high concentrations and are apparently not as continuous as those in the deeper pinnacle belt of zone I(b). They do, however, appear to be just as well developed individually. Most of our data on the pinnacles occurring between 75 and 90 m on the peninsular shelf are derived from lower resolution Uniboom seismic data, precluding any morphological comparisons to occurrences noted on side-scan sonar records.

The shallowest pinnacles are associated with larger positive morphologic elements of the shelf such as the spurs and other linear ridges and banks common between the 40 and 70 m isobaths. The pinnacles most commonly occur on the crests of these ridges with those to the south being at somewhat greater depths. The shallowest prominences were noted on the southern extension of the eastern ridge of the Florida Middle Ground, although it is suspected that these may be karst induced rather than wholly constructional forms.

These pinnacles are interesting because of their unique morphology

which is apparently indicative of marginal environmental conditions favoring vertical growth. This form might be advantageous in terms of adapting to low intensity light and nutrient flux by allowing maximum surface exposure of the organisms comprising the buildups. The shallower occurrences on the shelf appear to be a late stage of development of coral-algal buildups after initiation of the last major transgression.

Type 4 ("hard") targets were common on the outer shelf and upper slope, the highest concentrations being noted south of 28°N. These are discussed in more detail in the section on Unidentified Targets, but it should be noted here that they often grade into the higher relief skeletal accumulations (type 3) described above. They may represent an incipient state in pinnacle development.

Comparisons of the west Florida carbonate terrace to other open carbonate shelves have been made by others and a recent succinct review was compiled by Ginsburg and James (1974). They showed that the relict surface sediments on the majority of open carbonate platforms are sand size and exhibit consistent patterns of predominant carbonate grains: inner shelf-molluscan sands; shelf edge - ooids, peloids and corralline algae; slope-planktonic foraminifera. With the exception of peloids, this is essentially the pattern of carbonate constituents present on the peninsular platform. They also noted that the surface deposits are not contemporaneous, the oldest being the shelf margin deposits.

With the exception of one radiocarbon date, the deposits of the west Florida shelf have received little attention in the stratigraphic sense. Because of similar character and recent history, the extensive information available from the work on the Yucatan shelf compiled by Logan et al. (1969) provides a baseline for interpretation of the late Quaternary - Holocene history of the west Florida shelf. Rezak and

Edwards (1972) suggested that the coral-algal prominences and banks on the Florida shelf are equivalent to the Holocene Arenas Veneer member of Logan's Yucatan Reef unit. Although detailed bathymetric coverage is available for the west Florida terrace, Rezak and Edwards found correlations between terrace levels of the two platforms difficult. They did propose that the 55 m and 85 m terraces of Jordan and Stewart (1959) might be correlatives of the 30 and 52 m terraces of the Yucatan shelf. This seems unlikely unless the rate of subsidence on the west Florida terrace exceeded that of the Yucatan shelf by more than 2 m/1000 yrs. during the past 13,000 years. This rate is about two orders of magnitude greater than subsidence rates suggested by Emery and Uchupi (1972, Figure 324) and on that basis alone the correlations of Rezak and Edwards seem untenable. Similarities in lithofacies suggest to us that terraces on the Yucatan shelf at 33-40 m, 57-70 m, and 100-150 m have correlatives at approximately equal depths on the west Florida shelf. The Progresso Blanket of the shallower terrace is roughly equivalent to the shell and quartz-shell sands of the Florida shelf. The shelf and slope faces of the Sigsbee Blanket are equivalent to the algal and oolite sands and the foraminiferal sand and silts of the west Florida shelf respectively. The Arenas Veneer member of the Yucatan Reef unit appears to correlate well with the coral-algal ridges, banks and shallower pinnacles we have mapped on the west Florida shelf; the latter have no emergent-reef equivalents as the growth rate of bioherms at the shelf break was apparently insufficient to keep pace with sea level rise during the Holocene transgression. The correlation chart (Figure 33) summarizes these proposed relationships.

Review of some of the results of the geophysical studies on the west Florida shelf presented in this section, and summarized on Figures 27, 28, 30, 31 and 33 should suggest the obvious utility of conducting

a side scan sonar reconnaissance of a shelf prior to designing a sampling program. Comparison of box-core and dredge sites with major acoustic texture zones and observed occurrences of "hard-bottom" types suggests that important gaps exist in the program's past design. On the west Florida shelf, major acoustic-textural subzones have not been subjected to sufficient (e.g., Zone Ib) or any (Zone IIa) sampling to provide realistic "ground truth". Although it can be argued that substrate texture is only a second order determinant of faunal distribution (Stanton and Evans, 1972), this is not proven for all cases and there is evidence that standing crop (mass/area) does vary with sediment type (Emery and Uchupi, 1972, Table 10, p. 324). Certainly hard, stable bottom favors proliferation of epibenthic communities characterized by attached fauna. Hard substrates are the principal areas where concentrations of valuable commercial and recreational bottom fisheries occur (i.e., snapper and grouper banks; see Taylor et al., 1973; Moe, 1970). Any deleterious effects on the banks could result in severe economic consequences to industries involved. Although it was not possible to wait for a geophysical survey before starting the present sampling program, this should not be used as an excuse to avoid expanding or redesigning the sample strategy in light of evidence now available.

Although it seems unlikely, in light of the fishing effort in recent years, the deeper pinnacle reef belt between 27° and 28°N (Figures 28 and 30) does not appear in any published listing of commercial banks exploited by U. S. fishing interest (Moe, 1970). The depth range and isolation of this reef belt within an area characterized by soft bottom suggests that important concentrations of bottom fish may occur there (a similar pinnacle zone south of the study area is listed as an important fishing bank). The point is, hard bottom areas of the west Florida shelf are insufficiently

known to accurately assess the impact of environmental changes that might be induced by offshore petroleum exploration and development. Unlike the terrigenous northern shelf, where hard bottom is usually absent except at the shelf break, the peninsular shelf might not derive the same net benefits from the artificial "reefs" provided by drilling and producing platforms in promixity to areas with existing prolific hard bottom ecosystems.

Side-scan sonar reconnaissance also provides direct and indirect information on substrate mobility and near-bottom energy conditions through detection of various types and scales of bedforms and other structures of hydrodynamic origin. These are described and discussed in the following section. Prior knowledge of the general distribution of these diagnostic features would be invaluable for program design, aiding elimination of gross omissions which can easily result from a less rigorous approach.

Perhaps Flemming (1976) best stated the applicability of side-scan sonar to reconnaissance studies when he stated "(side-scan sonar data from) reconnaissance cruises can provide valuable background information but will not suffice for detailed interpretations. Utilizing such information, specific problems can be defined on a local or regional scale for a systematic approach within conventional survey procedure, thus optimizing and substantially improving costly scientific ventures."

5.5 Discussion and Conclusions - Northern Shelf (Zones I, IV, V)

No published investigation of the northern shelf was based upon an adequate number of samples to allow a detailed delineation of textural trends. However, several studies have been published showing broad trends in this region. Upshaw, Creath and Brooks (1966) sampled the shelf and slope west of DeSoto Canyon and mapped broad trends in sediment texture. They show fine sediment which generally coincides with Zone I(a) and (b). They then mapped trends showing sediments on the open shelf having

pronounced textural gradients, coarsening from west to east and south to north and this generally agrees with textures in Zone IV(a)-(d), (Figure 30). Ludwick (1964) studied sediments along three transects between Horn Island and Mobile Bay and his results agree with both the sonar and box-core data. Gould and Stewart (1955) on the basis of one transect south of Mobile Bay indicated there were no textural trends on this portion of the shelf. This probably resulted from the study of too few samples, as within trends sonar showed a patchy distribution of several sediment textures.

East of DeSoto Canyon McLeroy (1972) found the shelf to be composed of sand with admixtures of gravel, and fining rapidly seaward near the shelf edge. Sonar textures agree with his data, showing sediment textural zones in IV(e)-(f) to be distinct but not in linear trends (Figure 30). However, both data indicate that a gradational to abrupt fining of texture seaward begins near the shelf edge. Gould and Stewart (1955) made one transect south from Panama City, which agreed well with this study.

Only Ludwick and Walton (1957) report sampling the slopes of DeSoto Canyon. Their report of fine sediment in this area with 2 major reef pinnacle trends agree with both the sonar and box core date. Also, their transects through the pinnacle areas which showed a coarsening of the sediment in the pinnacle zone agrees with sonar indications.

Bedform Maps

6.0 Introduction

The response of the seafloor to hydrodynamic forces is revealed by patterns of topographic irregularities known variously as ripples, dunes and sand waves. The presence of such bedforms is a valuable but not unambiguous indicator of areas where waves or currents have affected the

sediment and presumably the associated biota. Side scan sonar records, augmented by Precision Depth Recorder profiles, were used to detect bedforms characteristic of bottom affected by current or wave activity. The classification employed in this report follows the system based on the simple dimensional criteria proposed by Reineck and Singh (1973). In their scheme, three size categories are defined on the basis of wavelength ($\lambda$-distance from crest to crest) and ripple index (R.I.=wavelength/amplitude) as follows:

Giant scale: $\lambda$>30 m; R.I. usually 30 to 100

Large scale: $\lambda$1-30 m; R.I. usually 15 to 30

Small scale: $\lambda$<1 m[(1)]; R.I. usually 5 to 15

One other bedform category, which we have designated "low-relief swells" was encountered on the Peninsular shelf. The term "low-relief swells" indicates very gently undulating bottom composed of sediment hills having apparent wave-lenths (measured along the profile) that range from a few hundred to a thousand meters. The corresponding wave heights are usually 1 to 2 meters, resulting in a R.I. much greater than 100. Ripple indices of this magnitude indicate a relatively flat surface. However, where present, the low-relief swells contrast with areas having no undulations and significant trends are evident in plots of this predominant direction of asymmetry (direction of the steepest dipping face).

Two subcategories were added to designate specific types of large

---

(1) To conform with SSS resolution at the slant ranges used in this survey, the boundary between large and small scale features has been modified from 0.6 to 1.0 m. The 1.0 m boundary also seemed consistent with a natural break in the population studied, i.e., the large scale forms usually exhibited $\lambda$>>1.0 m, and occurred in much lower densities and had longer, more continuous crests.

scale bedforms. These additional designations include "honey-combed" or reticulated bottom and possible rhomboid megaripples (Figures 37 and 38). Reticulated bottom is believed to indicate either lunate or lingoid megaripples. Both interpretations are tentative since no "ground truth" was available in the form of physical evidence (e.g., bottom photos) or identifications of similar features in the literature.

Side scan records were inspected for the above mentioned features and their locations were plotted on the 1:250,000 scale charts provided by the navigation contractor (Figures 1, 2 and 3). These data are summarized on Figures 34, 35 and 36. The "low relief swells" were identified from a compilation of ripple indices of all bedforms with relief greater than or equal to one meter and the areas characterized by abundant swells were plotted on the appropriate maps. The predominant direction of asymmetry is indicated by the arrows on the 1:1,000,000 sketch map (Figure 39).

The bedform maps provided only clues to the hydrodynamic forces operating on the shelf. Widely spaced data corridors did not allow determination of the extent of sand wave fields, and the orientation of certain transects was not conducive to detecting smaller bedforms. However, in the absence of more specific data such as bottom current measurements, these maps provide the only regional indicators of near-bottom dynamic forces operating on the MAFLA shelves.

The basic current generating forces on the shelf are: meteorological disturbances, tides, density differences in water masses and intrusion of oceanic currents (Swift et al., 1971). Bedforms can either result from the effects of one or any combination of these forces if the magnitudes are sufficient. Storms, due either to hurricanes or fronts, are considered most important in initiating sediment transport on shelves in

general (Swift et al., 1971), and are probably the major cause of bedform development on the peninsular shelf.

Other forces such as strong tidal currents (Back, 1970), and the eastern Gulf of Mexico Loop Current must also be considered. The present data base precludes any approach beyond broad generalizations regarding the genetic significance of bedform types observed at specific localities. It is hoped that the following observations and the accompanying maps will provide a base for investigations emphasizing the effects of different current generating forces and directions of major sediment transport on the MAFLA shelf.

6.1 Results - Peninsular Shelf

Five zones can be delineated on the basis of occurrence and distribution of various types of bedforms (Figure 39) and, the boundaries and characteristics of each zone are presented in this section. Possible origins and relation to sediment transport are outlined in Bedforms - Discussion and Conclusions.

Zone A extends along the west coast of peninsular Florida, from Charlotte Harbor to the vicinity of the Suwanee River. Its seaward boundary approximates the 20 m isobath. This zone is characterized by patches of large to giant sand waves. Most of these sand waves are sinuous and exhibit high backscatter levels in associated troughs (presumably due to coarser sediment) and trend northeast-southwest (subordinate east-west and southeast-northwest trends are also present).

Within Zone A, two areas exhibit striking bedform development. The first lies seaward of the Suwannee River along profile 22, between the 10 and 20 m isobaths (Figure 39). Along this profile, approximately 30 km of successive giant and large scale bedforms were present. These sand waves were characterized by sinuous crests that trend NE-SW with a

relief of approximately one meter. Exact height could not be determined due to the effect of ship motion of PDR resolution.

Figure 40 shows a portion of the sonograph along profile 33, illustrating the difference in bottom types between the crest and trough. These features are emphasized by the higher backscatter levels of the material in the flanking troughs. Also apparent is the acoustic signature of what is thought to be an unknown biologic community(ies) located on the flanks of the sand wave (see section on Unidentified Targets). This signature/ community is usually very sparse but occasionally covered an entire bedform. Such occurrences may indicate that the bedforms are the result of a much earlier event, such as a hurricane, and that the biota has subsequently been re-established.

The other area of striking bedform development was located off Tampa Bay. Numerous giant to large scale bedforms were observed seaward of the mouth of the Bay suggesting a possible relation to locally strong tidal currents. Other patches of giant to large scale features occur along the coast from Charlotte Harbor to the Suwannee River but are not as numerous, except on profile 22, nor do they exhibit the relief of those in the vicinity of Tampa Bay(see NOS bathymetric sheets NH17-10 and NG17-1).

Zone B lies seaward of Zone A, extending to depths of approximately 70 m in the south. North of the Suwannee River, in the Big Bend area, Zone B characteristics are encountered at shallower depths. The seaward boundary, north of 29°N, extends to a depth of 30 m only. Zone B is predominantly flat with areas characterized by numerous "low relief swells". The abundance of swells increases to the north as does the average relief, the latter approaching values characteristic of giant scale bedforms. A few isolated patches of giant, large and small scale features were noted in this zone, but based on present data, these occurrences were considered

relatively insignificant.

Predominant asymmetry is shoreward on profiles oriented normal to the coast. The only exception is profile 24, and it revealed an extremely flat bottom with very few bedforms of any type.

Zone C has been subdivided into subzones $C_1$ and $C_2$. Both are characterized by abundant small scale bedforms with the difference between the two subzones being based on distinct differences in depth of occurrence and population density (i.e., in subzone C, small scale bedforms are more numerous and occur at much shallower depths).

Subzone $C_1$ is located in the Florida Middle Ground region and extends northward toward St. George Island. Depths range from 20 to 40 meters. Small scale bedforms are abundant along most profiles. Along the crest of the Florida Middle Ground ridges (Figure 41) they trend approximately north-south while farther to the north, the trend becomes northwest to southeast. Large scale bedforms of the honeycombed and rhomboid types were present on profile 29 (see Figures 35 and 36).

$C_2$ is located south of the Florida Middle Ground area and extends into deeper water. Most prominent are the small scale bedforms along profiles 13 and 14 that trend approximately east-west at depths of 43 to 62 meters. Further south, along profiles 10 and 5, faint traces of small scale bedforms were present at depths of 60 to 70 meters. These were oriented approximately northeast-southwest and are poorly defined on the sonographs since the ship's course was not parallel to the trend of the crests.

The location of the majority of bedforms in Zone $C_2$ correspond to the crests of the "spits" described by Ballard and Uchupi (1970). Profiles 13 and 14 are normal to the axis of one spit further south (see Bathymetry).

Zone D includes the outer peninsular shelf and upper slope between 26°30' and 29°N. This zone is characterized by a smooth, inclined bottom with scattered areas of low relief swells and large scale bedforms. Interesting features were noted on profiles 3 and 30. On profile 3, between 120 and 140 m, a rolling, hummocky topography (Figure 42) was present. On profile 30, where it crossed the seaward flank of a cuspate foreland south of Cape San Blas (see Ballard and Uchupi, 1970), hyperbolic traces were observed between 105 and 130 meters (Figure 43). These large scale bedforms are similar to those associated with contour currents in much greater depths reported by Shepard et al. (1976), Damuth (1975) and Hollister, (1974).

Zone E is centered around Cape San Blas at depths of 30 to 80 meters. This zone contains the highest concentration of bedforms of all types. The giant scale features in this area are the largest so far surveyed on the peninsular shelf, with relief as great as seven meters. Superimposed on the giant scale features were numerous large and small scale bedforms. Orientation of the small scale features was approximately northeast-southwest which is normal to the crests of the giant scale features.

These profiles indicate that the predominant large scale bedforms in this area were of the "honeycombed" type, and these were commonly superimposed on the flanks of giant sand waves (Figure 37).

6.2 Results - Northern Shelf

Seven major bedform types were found on the northeastern Gulf of Mexico continental shelf between Cape San Blas and Horn Island: (1) predominately flat bottom; (2) low-relief swells; (3) small sandwaves; (4) large sandwaves; (5) giant sandwaves; (6) irregular-hummocky topography; and (7) reef and reef pinnacles. Although combinations of several bedforms may be found in many areas of the shelf, it has been possible to divide the shelf into six

bedform zones: (D) predominately smooth, which may contain reef and reef pinnacles; (E) giant sandwaves; (F) predominately low-relief swells; (G) low-relief swells and large sandwaves; (H) irregular-hummocky topography; and (J) transition zone.

Zone D, Predominately Flat Bottom

Zone D is charactized by predominantly smooth bottom. This zone type dominates the northern shelf. Three areas are made up of smooth or nearly smooth bottom.

Area $D_1$ (Figure 39) is located seaward of Cape San Blas, beginning at a depth of 15 m near the beginning of geophysical profile 34 and ending near the 30 m isobath. An almost symmetrical 4.5 m amplitude sandwave is near the center of the area and another one meter in amplitude is located near the intersection of geophysical profiles 34 and 38. A field of low-relief swells is located between s.p. 80-90 and another smaller area at s.p. 321 on profile 38.

Area $D_2$ (Figure 39) is basically the northern end of DeSoto Canyon. Most of this area consists of the canyon walls and within area ($D_2$) several outcrops of reef and reef pinnacles. Reefs and pinnacles are most abundant on profile 42 on the western slope of DeSoto Canyon from 70 m to the 275 m isobath. North of this, on profile 52, is a small pinnacle area between 60-70 m. To the east of this, a small pinnacle area occurs on the opposite slope at 80-90 m. To the southeast, on profiles 35 and 38, well developed reef and pinnacle zones are near the 40 and 60 m isobaths on the former profile and 40 m on the latter profile. Along profile 34, well developed reefs and pinnacles occur at depths of 45-55 m. In addition to the pinnacles, the smooth bottom surface is broken once on the northeastern slope of DeSoto Canyon along profile 52 (near s.p. 285) by a small zone of low-relief swells and landward of this (from s.p. 325

to 340) by an area of small sandwaves. A small zone of large sandwaves is located to the south at the intersection of profiles 36 and 38.

Area $D_3$ (Figure 39) is located south of Mobile Bay, extending westward to near the Chandeleur Islands. This area is essentially flat and no bedforms occur in the southern part with the exception of some low-relief swells near s.p. 56, 85, and 89 on profile 47. To the north, other bottom features become more numerous. On profile 50, large sandwaves ocur in the vicinity of s.p. 116 and 121. Along profile 44, low-relief swells occur at s.p. 5-12, 76, 119-139; giant sandwaves between s.p. 81 and 88; and irregular-hummocky topography between s.p. 88 and 100.

Zone E, Giant Sandwaves

Zone E is characterized by giant sandwaves (Figure 39).

Area $E_1$ (Figure 39) is a linear zone trending almost east-west and is located to the southwest of Panama City. Separating sub-area $E_1$ and $E_2$ is a zone of low-relief swells (profile 39 between s.p. 129 and 145 and at s.p. 111-113) and scattered small areas of reticulated bottom are present.

Area $E_2$ (Figure 39) is located near the shelf edge west of Cape San Blas. One area of low-relief swells occurs on profile 34 from s.p. 150 to 160. Reticulated bottom is present in the troughs between the giant sandwaves over most of the area.

Zone F, Low-Relief Swells

Zone F (Figure 39) is an area of low-relief swells located south of Panama City and west of Cape San Blas. It extends from near the shelf edge to just landward of midshelf. One small area of smooth bottom occurs between s.p. 275 and 291. Most of profile 35, between s.p. 75 and 125, is characterized by low-relief swells although a few scattered

giant sandwaves are present. On profile 39, giant sandwaves occur between s.p. 85 and 89. Several areas of reticulated bottom occur in this area. These are located on profile 39 from s.p. 21 to 55 and 74 to 79 and also on profile 38 between s.p. 292 and 312.

Zone G, Low-Relief Swells and Large Sandwaves

Zone G (Figure 39) is located on the outer one-third of the continental shelf southwest of Panama City. This area is characterized by a mixture of low-relief swells and large sandwaves. Low-relief swells are more numerous in the north along profile 52 and are about equal in number to large sandwaves near the middle of the zone along profile 40. Large sandwaves are more numerous in the south along profiles 35 and 36. One small area of flat bottom occurs on profile 36 from s.p. 65 to 75 and an area of giant sandwaves is present from s.p. 75 to 77. An area of irregular-hummocky topography is located on profile 52 between s.p. 396 and 400.

Zone H, Irregular-Hummocky Topography

Zone H (Figure 39) is characterized by an irregular-hummocky topography which is well developed in two areas.

Area $H_1$ (Figure 39) is west of Panama City and extends from near shore to approximately midshelf. Several other bedform types occur in this area - smooth bottom along profile 40 from s.p. 92 to 97 and on profile 52 from s.p. 539 to 541; low-relief swells on profile 52 from s.p. 530 to 539; small sandwaves on profile 52 from s.p. 522 to 530; and large sandwaves on profile 40 from s.p. 51 to 59. On the northern shelf, reticulated bottom is most common on profile 52 from s.p. 482 to 522 and 541 to 579 and profile 40 from s.p. 0 to 35 and 59 to 91.

Area $H_2$ (Figure 39) covers most of the region between Pensacola and Mobile Bay. Numerous small areas of smooth bottom occur throughout the

area, becoming more numerous to the north. On profile 49, smooth bottom occurs from s.p. 40 to 43; profile 42, s.p. 105, 131 to 135; and profile 43, s.p. 35 to 40, 41 and 45 to 48 and 55-71. Smooth bottom also occurs along profile 51 from s.p. 73 to 80, 106 to 110, 112 to 121 and along profile 52 from s.p. 10 to 18, 50 to 61, and 98 to 100. Scattered zones of reticulated bottom occur in bathymetric lows profile 51, s.p. 125 to 131; profile 52, s.p. 1 to 118 and 123 to 132.

Zone J, Transition Zone

Zone J is a transition zone made up of several combinations of bedforms.

Area $J_1$ (Figure 39), located west of Panama City, is made up of smooth bottom, low-relief swells, small and large sandwaves and irregular-hummocky topography.

Area $J_2$ (Figure 39) is located south of Pensacola and extends south southwestward subparallel to the shelf break. To the south, low-relief swells dominate, while small sandwaves are dominant to the north. Reticulated bottom is generally found in troughs between sandwaves.

Area $J_3$ (Figure 39), south of Mobile Bay, is a combination of smooth bottom, low-relief swells and irregular-hummocky topography.

6.3 Bedforms - Discussion and Conclusions

Any genetic interpretation of the observed bedforms, requires consideration of the possible forces operating on the shelf and the energy needed for formation of a particular type. Swift et al., (1971) outline the hydraulic regime of the continental shelf (Figure 44) and considers the most important component to be meteorologically induced currents. Although the depth to which waves can effect the bottom has been debated in the past, it has been shown by Hadley (1964) that appreciable currents are generated to depths of 200 meters by force 10 gales (Beaufort scale).

Sternberg and McManus (1972) report that bottom currents frequently exceeded speeds of 40 cm/sec (and as high as 80 cm/sec) at a depth of 80 m on the continental shelf off Washington state. These currents were attributed to wind stress induced during storm condition. The motion set up by waves and tidal currents is predominantly oscillatory with residual currents causing net transport. Density and oceanic currents are predominantly unidirectional, but usually are not as strong as the other forces. The superposition of one current upon another, however, can create a significant resultant. According to Swift _et al._, (1971), wave trains capable of suspending significant amounts of sediment for transport across the shelf, and generating sufficiently intense residuals, occur only during rare storms.

Figure 45 is the classic Hjulstrom diagram depicting average speeds needed to erode, transport and deposit sediment of a particular diameter. Sternbert (1972) cautions against strict application of such a diagram (which is based on data from flume studies) to the marine environment where boundary conditions can be quite different. This type of diagram however does provided a rough estimate of current speeds needed for sediment transport. From this diagram, it can be surmised that fine sand requires minimum speeds on the order of 35 cm/sec for initial movement. Sternberg and McManus (1972, p.191) support this value stating, "a speed of 35 cm/sec one meter of the bottom is sufficient to erode and transport most sand sized material." Factors determining the type of bedform that will result if this threshold is exceeded for a long duration are highly complex, and at present far from being understood (Allen, 1970). The most practical method of estimating the threshold of formation of an observed bedform of known type is by comparison to analagous bedforms that have been correlated with current speeds.

Giant sandwaves with relief up to seven meters, occurring at depths of 55 meters, were associated with near-bed current speeds greater than one knot (51 cm/sec) by Stride and Chesterman (1973). Kenyon and Stride (1970) found large to giant scale bedforms in an area where currents ranged from 1.24 to 2.5 knots (64 to 128 cm/sec). Loring (1970) attributed large scale sandwaves to currents in excess of one knot (50 cm/sec). Accordingly, we estimate that currents on the order of 50 to 100 cm/sec were probably required to form the majority of large and giant scale bedforms on the peninsular shelf.

The giant to large scale bedforms of Zone A are probably the result of multiple processes. The shallow depths (less than 20 m) indicate that the sea floor is susceptible to wave activity, even under moderate conditions. In the vicinity of bays, tidal influences will play a significant role in creating sandwaves. The patchiness of sandwave fields may be due to the paucity of sediment as evidenced by the numerous outcrops (see <u>Texture Maps</u>). Direction of sediment transport, as indicated by asymmetry of the bedforms, is highly variable along the coast. Long stretches of one predominant direction of asymmetry may indicate sediment transport cells along the coast.

The bedforms in the vicinity of Cape San Blas may represent more than one hydraulic regime. Giant sandwaves are found on profiles 31, 32 and 33. On profiles 31 and 32 the crests strike predominantly northwest while on 33 they strike northeast. A relief of 3 to 4 m is not uncommon. (7 m being the maximum observed). Superimposed on the flanks of many giant sand waves are the large-scale bedforms which produce the "honeycombed" signature noted earlier (see Figure 37). Small-scale bedforms occur seaward of the giant sand waves. The giant-scale forms were probably produced under extreme storm conditions. Their abundance and relief may mark the

passage of hurricanes (over 10 reported in this area since 1917; Jordan, 1973). The large to small-scale sand waves may have resulted from less severe conditions induced by frontal passage or some other unidentified current operating in the area.

Zone C designates an additional area of near-bottom current activity. The two subdivisions $C_1$ and $C_2$, although characterized by the same type of bedforms, may indicate different processes. The northern zone, $C_1$, is in shallower water and would be more subject to wave activity. Reports of strong tidally induced currents (up to 100 cm/sec across the crest of the Florida Middle Ground reefs; Back, 1972) suggest an alternative mechanism for many of the bedforms. These currents were observed in association with strong thermocline development during the summer months.

To the south, in Zone $C_2$, small scale ripples might be related to tidal forces similar to those observed on the Florida Middle Ground or they may be related to the intrusion of Loop Current water on the shelf Rinkel (1977) reports the presence of the Loop Current in this vicinity. These bedforms commonly occur in deep water (greater than 60 meters) and the crests tend to be oriented perpendicular to the bathymetry, implying north or south flow. Farther south the bedforms trend more toward the northeast-southwest indicating a possible northwest or southeast flow.

Side-scan sonar records from Zones B and D show very little evidence of current activity. The most prevalent bedforms are the low relief swells and these features are hard to interpret in terms of current generating forces. They may be the result of storms or the long term effects of low velocity currents and some are possibly relict. The swells on the inner shelf often correspond to areas with patches of fine sediment on a coarser matrix. These may be composed primarily of finer material derived from the relict veneer. There is a general onshore trend of asymmetry

of these features across Zone B, possibly indicating net shoreward sediment transport. At the outer boundary of Zone B, and in Zone D, no consistent asymmetry was noted. Smaller scale bedforms may be lacking on these swells due to bioturbation of the "softer" sediments. It is also possible that lower reflectivity also prevents detection of small scale forms. A mottled bottom signature, possibly caused by increased bottom roughness (see, Unidentified Targets - type 4 bottom), was common in Zone D seaward of the shelf break. The similar distribution trends of mottled bottom and the small scale ripples characteristic of Zone C suggest that small scale bedforms may be present, but below the threshold of sonar detection (ca. 1.0 m in this study).

Evidence of a strong contour current along the continental slope was observed on geophysical profile 30, in depths between 102 and 130 meters. Hyperbolic traces indicate large scale sandwaves with crests parallel to the isobath. Similar traces were detected on Uniboom profile U-9 of the historical data section. This second example lies to the south of depths of 110 to 120 meters. Analagous structures believed to be the result of major submarine currents have been reported in the literature (e.g., Shepard et al., 1976 along the west coast of Mexico; Damuth 1975 and Hollister et al., 1974 in the Atlantic). The reported structures were considerably larger and occurred at different depths but their form ratio and relationship to the bathymetry is similar. Consequently, we believe the hyperbolic traces we note on the upper slope indicate the presence of a major current probably the eastern Loop Current.

Following Jacobi et al., 1974, we conclude that these features were formed by currents rather than mass wasting because the troughs appear to be linear and trend parallel to the contours, the high backscatter levels suggest finer sediment has been removed or the existence of small-scale

bedforms and they occur on low gradient slope (1 to 100).

In summary, bedforms on the west Florida shelf provide evidence for a wide range of hydraulic conditions. The inshore area, from the Suwannee River to Charlotte Harbor (Zone A), has numerous giant and large scale bedforms that probably result from the complex interaction of waves and tides. In the vicinity of Cape San Blas, giant sandwaves may indicate the effect of past hurricanes while smaller superimposed bedforms are probably indicative of prevailing current(s) of undetermined origin. Areas of small scale bedforms occur on the center of the shelf (Zone C), some at depths greater than 60 meters. Some of these may be the result of strong tidal currents. Finally, unusual structures resembling contourite dunes are observed between 28° and 29°N in depths between 100 and 130 meters.

A current magnitude of 50 to 100 cm/sec is roughly estimated as the range necessary to form the majority of bedforms observed on the shelf. The forces generating these currents, in the presumed order of importance are storms, tides and possible incursions of the Loop Current on to the shelf. Storms are probably most effective on the shelf landward of the shelf break while the outer shelf region is probably affected at a frequency of only once every few years (Curray, 1960). Tides are strongest near estuaries although evidence has been presented by others for strong tidal effects in deep water. The Loop Current might be an important factor from the outer shelf landward to the shelf break, but details of its behavior and strength on the shelf have yet to be determined.

Problems requiring further research include determination of the mechanisms generating the small scale features in the vicinity of Cape San Blas and along the shelf break (in $C_2$), the high concentration of giant bedforms seaward of the Suwannee River and Tampa Bay (Zone A) and the

possible contourite dunes found between 100 and 130 meters in Zone D. Positive identification of the "honeycombed" pattern as lingoid mega-ripples would be of interest as these are considered rare forms by Reineck and Singh (1973).

Bedforms on the northern shelf are generally rather simple and not diverse. The floor and slopes of DeSoto Canyon are smooth and featureless as a result of fine sediment deposition. A reef and reef pinnacle zone around the canyon breaks the otherwise smooth surface. The pinnacles are partially to completely buried, and the exposed ones are not undergoing slow burial. This burial is from fine, terrigenous sediment transported into the area from disintegration of the pinnacles themselves.

The shelf landward of DeSoto Canyon has a well-developed relict topography which is completely smoothed and buried on the western side of Mobile Bay by the St. Bernard prodelta. The rest of the shelf on the west side of the canyon is rough and irregular but not as a result of partial to nearly complete burial of the relict topography by recent sediments.

On the shelf east of DeSoto Canyon, some partially buried relict topography was observed, but most of the shelf is covered by sand waves of varying size. The largest are in the vicinity of Cape San Blas, as a result of the higher energy in that area.

6.4 <u>Unidentified Targets</u> - <u>Peninsular Shelf</u>

<u>Results</u>

Side-scan sonar reconnaissance resulted in a diverse catalog of unidentified acoustic signatures. No attempt is made to describe every variety of "acoustic problematica" encountered, but we believe it would be of value to future investigations to discuss types that were encountered sufficiently often to exhibit some distribution trends. In many

cases, these unidentified signatures are believed to indicate dense, living, epibenthic communities, while others may be relict concentrations of skeletal debris. Even the latter are probably characterized by extant deep-shelf faunal assemblages.

Figure 46 summarizes major occurrences and distribution trends of the eight most common types of unidentified sonar signatures encountered on the peninsular shelf. The region south of 28°N, between the 60 m and 200 m isobaths, contains the greatest abundance and diversity of the common types. These include: (1) large depressions greater than 6 m in diameter; (2) linear clusters of mixed, small to large targets; (3) small to large, high reflectivity targets, some exhibiting pin-point shadows in the center, and (4) "mottled" bottom.

Type (1) Targets - Large Depressions

Table IV lists the location, depth, number of individuals, density and maximum diameter of large crater-like depressions (Figure 47) observed on the peninsular shelf. All were encountered between 60 m and 100 to 130 m. Concentrations ranged from single sightings to nearly 100 individuals per square kilometer. Due to the subtle relief, the depth of the central depression was difficult to estimate. Because of ship motion the true structures could not be resolved on the PDR. A few estimates of relief were possible when the side-scan sonar fish passed directly overhead, allowing definition by the vertical sound lobe. These direct crossings indicate that the central depressions are asymmetric and apparently less than two meters deep. A characteristic of all type 1 depressions is the associated border or halo of higher reflectivity material. They do not appear to be restricted to a specific sediment type, occurrences having been noted in acoustic-texture Zones I and II (see Figure 30).

Table IV. Occurrences and Characteristics of Type 1 Unidentified Targets - Large Depressions

| PROFILE | Shot Points | Depth(m) | Number of Individuals | Density per $km^2$ | Max Diameter(m) |
|---|---|---|---|---|---|
| 3 | 6-12 | 76 | 15 | 27 | 17 |
| | 41-44 | 77-78 | 10 | 35 | 17 |
| | 221-227 | 121 | | | |
| | | 121 | 14 | 31 | 15 |
| 4 | 27-58 | 102-120 | 53 | 22 | 21 |
| | 102-103 | 86 | 1 | 13 | 15 |
| | 106-107 | 88 | 5 | 66 | 15 |
| | 118-122 | 76-77 | 26 | 85 | 12 |
| | 130-131 | 73 | 4 | 52 | 15 |
| 5 | 150-160 | 66 | 72 | 94 | 15 |
| | 201-202 | 72 | 5 | 66 | 15 |
| | 223-224 | 74 | 1 | 13 | 12 |
| | 277-298 | 74 | 55 | 34 | 15 |
| 6 | 24-25 | 81 | 4 | 52 | 12 |
| | 87-93 | 124-125 | 6 | 13 | 15 |
| | 139-150 | 148-152 | 18 | 22 | 12 |
| 7 | 28-29 | 180 | 1 | 6 | 30 |
| | 180-220 | 134-128 | 110 | 18 | 15 |
| 8 | 83-84 | 144 | 2 | 16 | 18 |
| 9 | 172-180 | 78-76 | 55 | 56 | 15 |
| | 189-191 | 74-74 | 9 | 37 | 15 |
| 14 | 126-129 | 74-76 | 5 | 22 | 15 |
| 16 | 220-221 | 100 | 1 | 3 | 12 |

Inspection of subbottom profiler data revealed no consistent trends that might be relevant to their genesis. At about half of the locations 3.5 kHZ records were characterized by a "smeared" signature that has been found to be indicative of gas saturated sediments in other areas. If this is the case here, these depressions may have an origin similar to the "pock-marks" descirbed by King and MacLean (1970). They found circular cone-shaped depressions on the Scotian shelf in water depths averaging 180 m. The pockmarks ranged from 15 m to 45 m in diameter and occurred in densities of 45 to 200 individuals per square-kilometer. Central depressions were about 5 to 10 m deep and apparently originated by percolation of fluids. Although size and density characteristics of the depressions on both shelves are similar, the sediments differ; those on the peninsular shelf are more arenaceous. King and MacLean proposed that, during periods of active percolation, fine sediment (mediam diam. 0.003 mm) is suspended and transported away from the site by currents. Suspension and subsequent transportation of material from the central depression would explain the lack of rim development on the Scotian shelf examples. The depressions encountered on the west Florida shelf could have been caused by abrupt dewatering of underlying strata or periods of active percolation sufficiently intense to expel sediments but, in the absence of a competent transport mechanism, coarser material might have accumulated around the flanks, forming a "atoll-like" rim. Long inactivity and subsequent infilling may have subdued the initial relief of the depression. With the possible exception of seepage or springs, the trigger mechanism and evidence for development of such phenomena on carbonate shelves is lacking. We are unfamiliar with any documented reports of gas seeps or gas saturated sediment in the region these depressions occur.

With present data, it seems just as probable that type 1 depressions

may be explained biologically. They occur at the same depth range and in the same region on the shelf as the pinnacle reefs described in Acoustic-Texture Map. The rims may be the sites of increased skeletal production and accumulation which has resulted in the formation of a mini-atoll. Absence of appreciable water movement might stimulate such buildup geometry with the low flux of nutrients being compensated for by maximization of surface area. Figure 40 is an example of a similar signature encountered in shallow water (approx. 12 m) on profile 22. The largest inshore examples are about 15 m in diameter, approximating the size of the offshore depressions. The data preclude estimation of the depth of the central depression and, in fact, the acoustic-shadow may only be indicative of the lower reflectivity of the center. The targets on Figure 40 are believed to represent a living epibenthic community, and the high reflectivity rim is attributed to greater relief and/or different character of the organisms which occur around the margins of the community.

An anthropogenic origin (e.g. depth charges, perturbation during fishing operations) has also been considered for type (1) but their depressions, restricted depth range, abundance and association with other similar, but smaller, targets suggest otherwise.

Type (2) Targets - Linear Clusters

Table V lists the occurrences of type 2 unidentified targets on the peninsular shelf. The features consist of linear cluster (Figure 48) of circular high reflectivity patches commonly having central pin-point acoustic shadows. They occur at depths of 100 to 146 m and, although less common than type 1 depressions, their geographic range of 26°48' to 28°22'N is coincident and 3.5 kHz profiles show a substantial blanket of low impedence sediment at most locations with no apparent relationship of these targets to underlying structure although such a relationship is

not precluded. Type 2 targets probably have a biologic origin and may be relict. The linear growth habit may be a response to near-bottom hydrodynamic conditions, although it would be difficult with present data to hypothesize alignment normal or parallel to any incident current(s).

Type (3) Targets - Small to Large, High Reflectivity "spots"

On the seaward portions of most profiles and especially those south of 28°N, the bottom is characterized by abundant small to large "spots" of high reflectivity material (Figures 49 and 50). We are unable to observe any associated relief, although pin-point acoustic shadows commonly occur in the center of the targets. A few had shadows in front suggesting the possibility of scour around the base of a more resistant (indurated?) mass. This tends to be more prevalent on northern profiles. The smaller targets can occur in as high as 2000/km$^2$ (see Table VI). Small forms were not noted north of 27°30'N while the larger targets persisted in lesser number north 29°N. Subbottom profiler data show no relation of these targets to underlying structure. Both type 2 and 3 targets are probably concentrations of coarser skeletal material (relict?) and/or sites of dense epibenthic faunal development. If sampling should indicate that they are composed primarily of relict coral-algal skeletal debris, then they probably represent incipient pinnacle development.

Type (4) Targets - "Mottled" Texture

An unexplained bottom texture (Figure 51), common at depths greater than 70 m, has been labelled "mottled" bottom. Like type 1, 2 and 3 targets, it is more prevalent south 28°N. Table VII lists occurrence, depth range and linear extent along the profiles. No narrow depth zonation was noted; the range of occurrence was from 45 m to 150 m with the majority found between 70 m and 120 m. All shallower (45 m to 70 m) encounters were north of 28°N. The tendency to shoal to the north is

Table V. Occurrence and Depth Range of Type 2 Linear Clusters

| PROFILE | Shot Point | Depth (m) |
|---|---|---|
| 3 | 228-246 | 122-124 |
| 4 | 23-26 | 122-121 |
| 8 | 1-23 | 128-140 |
| | 34-36 | 141-142 |
| | 66-76 | 146-145 |
| 9 | 124-136 | 116-101 |
| 14 | 189-193 | 112-117 |
| | 199-206 | 123-130 |
| 16 | 203-207 | 106-106 |
| | 210-220 | 106-100 |

Table VI. Occurrence and Concentration of Small Type 3 Targets

| PROFILE | Shot Point | Depth (m) | Target/Density |
|---|---|---|---|
| 3 | 200-240 | 180-200 | 426 |
| 7 | 1-50 | 180-200 | 187 |
| 8 | 167-193 | 184-185 | 2001 |
| 9 | 19-54 | 148-175 | 861 |

Table VII. Occurrence, Depth and Continuity of Type 4 "Mottled" Bottom

| PROFILE | Shot Points | Linear Extent (km) | Depth (m) |
|---|---|---|---|
| 3 | 5-155 | 32. | 76-111 |
| | 175-200 | 7.6 | 114-117 |
| | 250-279 | 8.8 | 126-150 |
| 4 | 61-63 | 1.8 | 95-94 |
| | 70-74 | 1.2 | 90-86 |
| | 96-109 | 4.0 | 82-78 |
| | 115-155 | 12.2 | 78-67 |
| 5 | 148-220 | 22.0 | 68-74 |
| | 240-318 | 23.8 | 74-71 |
| 6 | 38-75 | 11.3 | 93-116 |
| | 14-22 | 2.4 | 76-78 |
| 9 | 137-153 | 4.9 | 100-86 |
| 14 | 125-215 | 27.4 | 75-150 |
| 16 | 190-201 | 3.4 | 125-112 |
| | 226-249 | 7.0 | 90-74 |
| | 262-272 | 3. | 56-62 |
| 30 | 265-284 | 5.5 | 81-91 |
| 31 | 93-96 | 0.9 | 78-60 |
| 32 | 4-8 | 1.2 | 88-85 |
| | 34-37 | 0.9 | 59-57 |
| | 56-64 | 2.4 | 47-45 |

analogous to the shoaling trend which differentiates bedform subzones $C_1$ and $C_2$ (see previous section Results - Peninsular Shelf).

The mottled pattern could be caused by increased roughness and consequently backscatter level (see Texture Maps) of the sea floor due to ripple development. If this is true, the wavelength of the ripples is below the resolution (ca. 1 m) of the sonar instrumentation at the slant ranges employed in this reconnaissance. The tendency of type 4 bottom to occur just seaward of bedform Zone C (see Figure 39) and to shoal to the north would seem to support this interpretation. However, the pattern may simply be due to a diffuse mixture of high and low reflectivity material which grades shoreward into the more discrete patchy units (Figure 52) typifying acoustic-texture Zone II and III landward of the shelf break.

Type (5) Targets - Coral-Algal Pavement

Profiles of the inner shelf, between 25 m and 60 m, indicate that few targets are present. Where they do occur they tend to be small and exhibit no detectable relief. The only region of abundant targets lies west of the Florida Middle Ground reef (Figure 46). These targets exhibit a "granular" high reflectivity signature which is suggestive of dense patch reefs or coral-algal pavement. Type 5 bottom often "caps" broad low relief sediment lenses. Similar signatures were noted on- profile 13 and to a lesser extent on profiles 11, 19, 22, 25 and 30. Many of the shallower occurrences may be exposures of underlying limestones.

Type (6) Targets - Epibenthic Communities

At depths shoaler than 25 m a variety of targets were present that prbably represent flourishing biologic communities (Figure 53). The type 6 signature is unusual in that it is evident on the Precision Depth Recorder as well as on side-scan sonar records. These patches exhibit a

unique "fuzzy" high reflectivity sonar return. Figure 53 illustrates this signature and Table VIII lists the distribution and depths of occurrence. The depth range is very restricted (7 to 11 m) and the best developed patches were encountered near the end of profile 21 in approximately 11 m of water. Because our 3.5 kHz profiles in shallow water were of poor quality due to ringing, any association of these targets with outcrops is difficult to determine. Most occurrences were related to slight rises that appear to be lenses of unconsolidated sediment. The Big Bend region is noted for its commercial sponge reefs (Storr, 1964) and these may be the origin of type 6 patches. However, this is speculation and the probable occurrence of these targets on unconsolidated sediment contrasts with observations that sponge reefs are restricted to hard bottom.

### Type (7) Targets - Epibenthic Communities (?)

Figure 40 illustrates another unusual signature that is believed to represent a living epibenthic community. It occurs to depths of 25 m on profiles 22, 24 and 25. Type 7 targets vary from circular patches 10 m to 30 m in diameter to blankets extending up to 300 m along a profile. This signature is commonly found on the flanks of large sandwaves and on apparent outcrops in intervening troughs. It tends to be more prolific at deeper sites (i.e., more dense and extensive). The similarity of type 7 signatures to type 1 large depressions have already been discussed.

### Type (8) Targets - "Mottled" Bottom

Another "mottled" bottom signature (Figure 54) occurs on profiles 19, 13 and 11. Type 8 mottling is not as extensive as the type 4 mottling of deeper water and differs in character and is composed, in part, of discreet small "spots". This bottom type occurs to depths of about 20 m and is commonly found in close proximity to extensive limestone outcrops suggesting

Table VIII. Occurrences and Depth Range of Type 6 Unidentified Targets - Epibenthic Communities (?)

| LINE | Shot Points | Depth (m) |
|---|---|---|
| 21 | 185-187.2 | 11 |
| | 214.8-216 | 10-11 |
| | 224-226 | 11 |
| | 240-242 | 10-11 |
| | 254.5-256 | 11-12 |
| | 330-330.3 | 8 |
| | 337.7-339 | 9 |
| | 359.9-360 | 8 |
| | 383-385.3 | 8 |
| | 400.1-400.9 | 7 |
| | 404-405.3 | 7 |
| 24 | 352.5 | 10 |
| 25 | 7.9-12 | 10-11 |

it may be residual debris or a fauna requiring a solid foundation.

There are a number of miscellaneous targets that occur at only one location. Because of their uniqueness, their importance in understanding the regional character of the shelf is considered subordinate and they have not been described.

Discussion

Eight types of "acoustic-problematica" are commonly encountered on the peninsular shelf. Three broad depth zones, bound by the 25 and 60 to 80 m isobaths, define major trends. These approximate the range of acoustic-texture zones I, II and III (Figure 30).

The deepest zone contains the highest diversity and abundance of targets including: large circular depressions, up to 30 m in diameter and two meters deep; large and small dark "spots", exhibiting little or no detectable relief; linear clusters of high reflectivity targets; and mottled bottom, extending up to 30 km along a profile.

The large depressions are perhaps the most provocative type. Their similarity to structures attributed to gas seeps on the Scotian shelf suggests a number of interesting implications including possible sources of hydrocarbon input to the peninsular shelf. However, the depressions on the Florida shelf differ morphologically in that they have an associated halo or rim of higher reflectivity material. Other origins, involving either mini-atoll development or groundwater seepage, are just as plausible with the present data base and samples of the material comprising their rim would clarify their origin.

The other unknown signatures described could also be of biologic origin, especially types 2 and 3. The "mottled" type 4 may be a mixture of textural types but similarity of north-south trend and association with bedform Zone C suggest that the signature is caused by small scale

bedforms, probably ripples, below our resolution limit. If these are bedforms of current origin, they indicate substantial near-bottom dynamic activity on the outer shelf south of 28°N. This may also be the reason for the prolific number of type 2 and 3 targets in the same region. It is difficult to avoid speculation that both the targets and the mottled texture may be related to the eastern Gulf of Mexico Loop Current. More detailed surveys of type 4 bottom at ranges allowing higher resolution may yield information relevant to the transport of the fine sediments which comprise the sea bed on the outer shelf and upper slope.

The abundance of targets south of 28°N may be more indicative of earlier hydrodynamic conditions. The outer shelf narrows north of 28°N (e.g., it is less than 5 km from the 60 to 100 m isobath at 28°30'N). Given a late-Wisconsin still stand at about 60 m, energy conditions to the north should have been high due to the lack of a broad ramp to dampen the effects of any incident waves of currents. Here coral-algal ridges are prominent. South of 28°N, a more "damped", lower energy environment should have prevailed and here we find smaller, isolated forms.

Between 60 m and 25 m, targets are generally rare; the only significant group occurring west of the Florida Middle Ground. These targets appear to be coral-algal pavement and they commonly cap sediment lenses. In general, targets between the shelf break and the 25 m isobath are smaller and exhibit less variety than those offshore or inshore. A number of signatures occur at depths shallower than 25 m. Types 6 and 7 are thought to indicate flourishing epibenthic communities. They are confined to the Big Bend region between Tarpon Springs and Apalachicola. Although the associated faunal assemblage is unknown, it seems likely that they are "sponge reef", and/or coral-algal reef communities. Additional data, particularly collections by dredging, diving, or the use of an underwater

Station 2106 - located 1500 m S of s.p. 6/170, depth 165 m

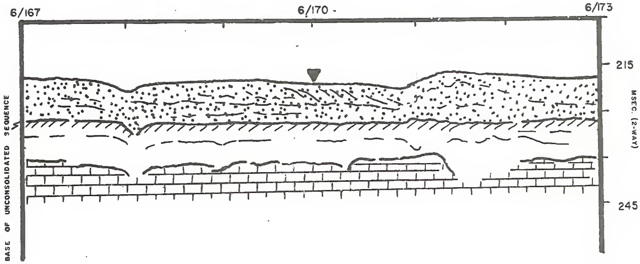
SSS - texture : uniform weak to moderate - the latter is associated with targets. Targets noted at s.p. 6/173.5, and s.p. 174.4-174.6 have halos of higher reflectivity material around their flanks. These may be small relict bioherms (Amphistegina assemblege? - see Section VI)

bedforms : four broad, low relief long wavelength swells noted between s.p. 6/165-175:
s.p. 6/165.5-167.85 (720 m x 1.6 m) symmetrical
s.p. 167.85-170.6 (840 m x 1.6 m) asymetrical E
s.p. 170.6-173 (730 m x 2.4 m) asymetrical E
s.p. 173-177 (1220 m x 2.4 m) asymetrical E

The first bedform appears to be bound by flanking depressions related to deeper structure (see below, s.p. 6/168)

Subbottom profiles - approximately 10 m of unconsolidated sediment overlying two concordant strong subbottom reflectors. The lowest unit appears to be karstified (or incised by channels). The former interpretation being preferred as this lies S of, and along, the same trend as a karst belt encountered along other transects

Internal stratification of the upper unconsolidated unit in the vicinity of s.p. 6/170 suggests seaward progration.

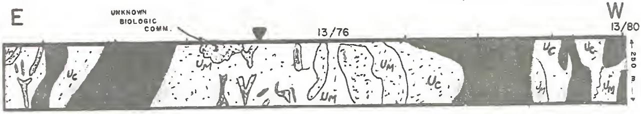


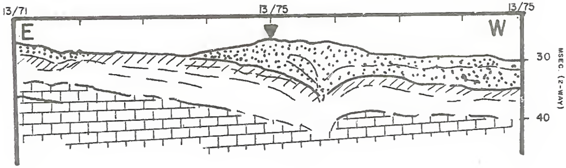
Station 2207 - located 450 m N of s.p. 13/75, depth 18 m

SSS - texture : highly variable moderate to strong (or hard), small dark targets between s.p. 13/74-75 of undetermined origin (large loggerhead sponges?)

bedforms : s.p. 13/75 is located on a large low relief sediment lens (900 m x 2.8 m). The bifurcating zones of higher reflectivity material in close proximity to the sampling site probable indicate coarser material lying in troughs between the sand waves that are superimposed on the sediment lens.

Subbottom profiles - Difficult to distinguish very coarse sediment from outcrops, but the 3.5 kHz profiles (not shown) indicate the first subbottom reflector outcrops at s.p. 13/73.6 and between s.p. 13/77-78. Judging from the "Boomer" profiles, much of the area shown as "solid black" on the SSS sketch is probably an exposure of coarse channel fill or lag underlying finer sediment. However, there is no reason to preclude the possibility of lithification. This valley is part of a larger complex extending from s.p. 13/56 to 13/83.



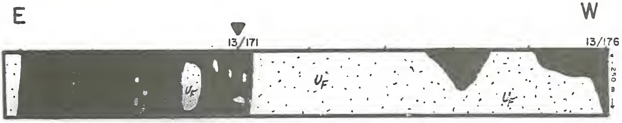



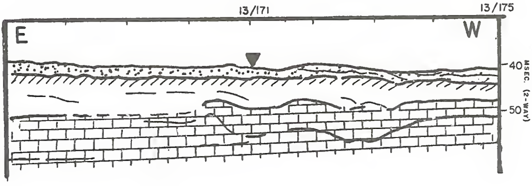
Station 2208 - located 600 m NW of s.p. 13/171, depth 30 m

SSS - texture : sharp boundaries were noted between exposed very high reflectivity sediment (or outcropping lithified sediments) and finer sediment. The finer sediments correspond to thin lenses developed on a shallow unconformity.

bedforms : s.p. 166.5-168 (460 m x 1.0 m) asymmetrical E
s.p. 171.5-173.5 (600 m x 1.2 m) asymmetrical E

Subbottom profiles - PDR has a distinctive smeared signature in areas which exhibit strong reflectivity on the SSS records (dark patches). Perhaps this is due to very irregular bottom texture such as shell hash or dense concentrations of hard-bodied organisms (or gas?). The "Boomer" profiles show this area to be the seaward portion of a broad filled valley complex which extends from s.p. 13/150 to 13/180. This system is deeply incised into the basal unit between s.p. 13/156-160 (note: the valley fill is symmetrical). The areas shown as outcrops or windows are probably very coarse lags exposed on the flanks of the major structure. Superimposed on these are very thin (1-2 m) fine sediment lenses which are probably reworked derivitives of the underlying unit.

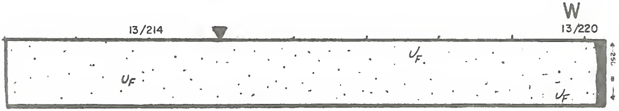


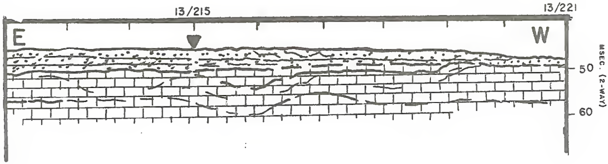



Station 2209 - located at s.p. 13/215, depth 34 m

SSS - texture : fine sediment lens about 1-2 m thick, flanked by coarser or lithified deposits to the E and W.

Subbottom profiles - PDR shows same "smeared" signature, that was present in the vicinity of station 2208 at the window/outcrop areas. Boomer profiles indicate 0.5 to 4 m of unconsolidated to poorly consolidated sediments overlying an irregular limestone surface. Of interest is the thin bedding apparent in the units underlying the fine sediment lenses (silt or clay Units?). Very strong sonar returns may correspond to exposures to coarse lag overlying the basal imestone.



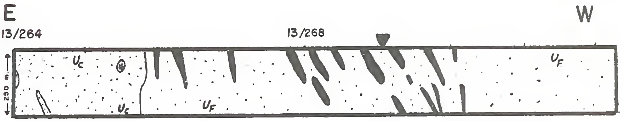



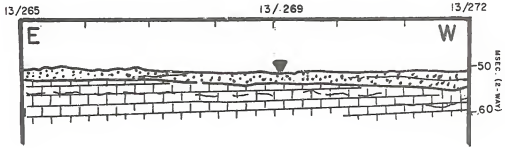
Station 2210 - located 1200 m NE of s.p. 13/269, depth 38 m

SSS - texture : slightly variable, generally high reflectivity from s.p. 13/264 to 266, and weak from s.p. 13/266 to 274 with coarser or hard bottom exposed in troughs.

bedforms : coarse sediment lens 264-267 (910 m x 1.2 m) fine sediment lens 270-273.4 (1040 x 1 m) asymmetrical W

Subbottom profiles - Windows definitely correspond to low areas having smeared PDR signature similar to that noted at stations 2208 and 2209. Boomer profiles indicate 1-2 m of unconsolidated sediment overlying lithified strata. Some bedding noted in upper unit. The "windows" may be coarse lag above the lithified surface. (Note that box-core stations 8 through 10 are located on a broad terrace between the 32 and 38 m isobath which is 16 km wide adjacent to profile 13 (slope 1:2700))



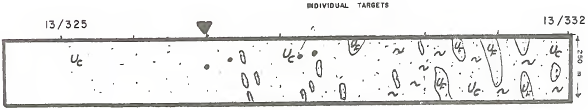



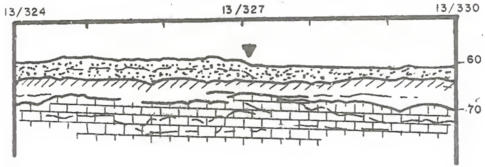
Station 2211 - located 300 m N of s.p. 13/327, depth 44 m

SSS - texture : strong backscatter levels, becoming variably strong with patches of weak bottom west of s.p. 13/327. (These patches increase in size west of s.p. 13/329).

bedforms : large low-relief swell between 324.6 and 327 (730 m x 1.6 m - asymmetrical W) corresponds to the coarser sediment designated in the sketch. The sonar signature on top of this swell suggests the occurrence of an epibenthic community. Some individual targets noted between 327 and 328 and at 331.8. Ripples present in coarse sediments west of relief structure. Ripples and N-S elongation of sediment patches may be indicative of periodic hydrodynamic activity at this station.

Subbottom profiles - two major acoustic units defined by strong reflectors overlying an irregular limestone surface. The upper unit is believed to be unconsolidated and is from 3 to 5 m thick. The high reflectivity of the top of the second unit suggests possible local lithification.

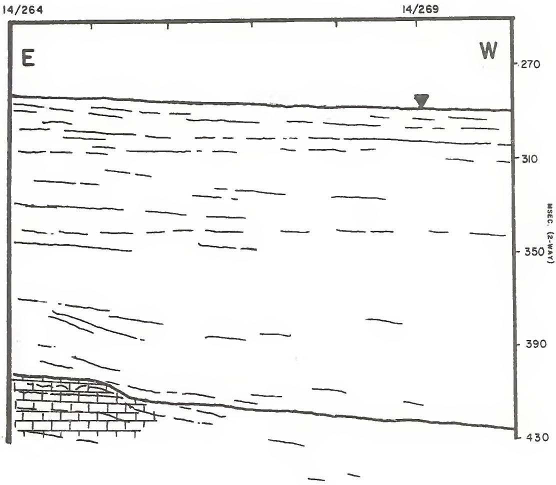


Station 2212 - located 11 km N of s.p. 14/269 (or 15/1). depth 216 m

SSS - extremely flat bottom with very weak sonar return indicating uniform fine sediments.

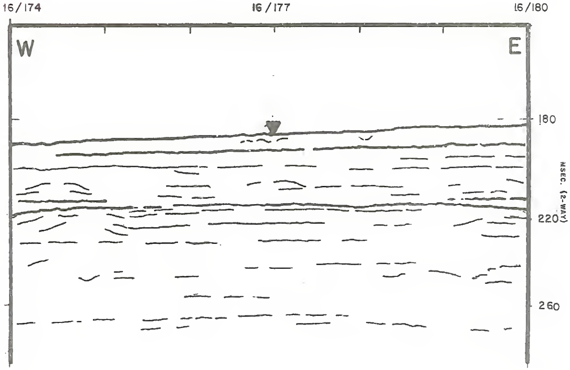
Subbottom profiles - very thick (120-130 m) unit of thin bedded sediments overlying strong acoustic discontinuity surface (probably middle Miocene - see Chapter 4).



Station 2313 - located 1500 m N of s.p. 16/177, depth 140 m

SSS - texture : Uniform weak backscatter levels, no bedforms detected

Subbottom profiles - Thick sequence of thinly bedded sediments. Upper 5-7 m probably represent Late Pleistocene to Recent deposits. The proximity of this station to the south flank of a large positive bathymetric anomaly centered about 500 m to the north (see NOS chart NH16-12) might be of interest in explaining any unusual constituents present in the samples. This anomaly may be due to the presence of one of the shelf edge bioherms that are more common further to the south at equivalent depths. The station location and the possible existence of southward flowing contour currents could result in some unusual components in the carbonate fraction (i.e., forminifera assemblage, invertebrate, skeletal fragments, etc.).

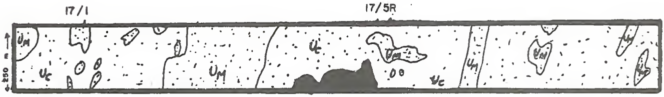


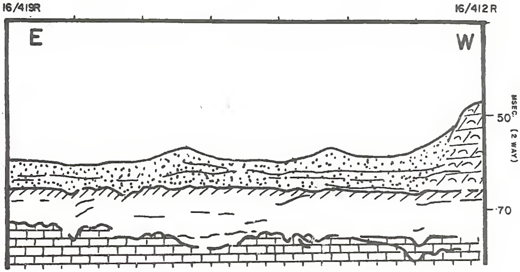
Station 2314 - located at s.p. 17/2R (or 16/419R), depth 44 m

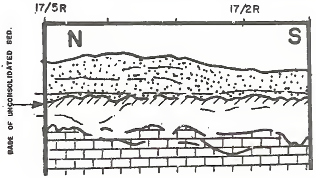
SSS - texture : predominantly high reflectivity bottom with large patches of moderate reflectivity

bedforms : some evidence of ripple development in coarser sediments but the signature is weak due to the heighth of the transducer above bottom. Bottom exhibiting lower reflectivity contains small targets which are believed to be mounds associated with burrowing organisms.

Subbottom profiles - This station is located in the pass between the western Middle Ground reef ridge and a large isolated pinnacle (see bathymetric sheet). Unconsolidated sediments should be 5 m or more thick, increasing to the southwest. Deeper basal limestone unit is very irregular - suggestive of a karren surface. Overlying this is the unit on which the western reef ridge has developed. This is also probably indurated but to a lesser degree, judging from the ease of penetration by the low energy seismic systems utilized.



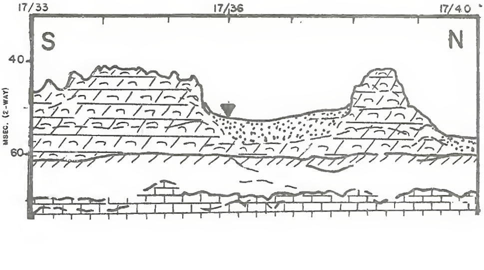



Station 2315 - located 300 m E of s.p. 17/36, depth 37 m

SSS - texture : strong to moderate reflectivity bottom between hard reef structures. Generally, the greater the distance from the reef, the lower the backscatter level (e.g., in the vicinity of s.p. 17/31). The coarser sands appear to be confined to the talus slopes adjacent to the reef and grade into finer sand.

bedforms : not shown on the sketch, are the impoverished areas of reef crest which contain patches of coarser sediment covered with well-developed symmetrical ripples (crests are oriented N-S).

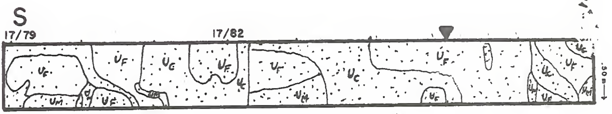
Subbottom profiles - Sample 2315 apparently was retrieved from a partially filled trough which incises the west ridge. This trough appears to be filled with 5 m or more of unconsolidated sediment (probably derived from the reef crest). The basal unit is very irregular suggesting karstification (see Station 2314 description).

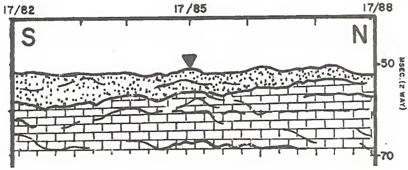



Station 2316 - located 300 m E of s.p. 17/85, depth 36 m

SSS - texture : highly variable from weak to strong. Overall, higher reflectivity bottom predominates with subordinate patches of moderate to weak; small mounds possibly associated with burrowing organisms, are present in the finer sediments.

Subbottom profiles : Unconsolidated sediments thin to the north, from 5.5 m at s.p. 17/82 to less than 2 m at s.p. 17/88. Underlying limestone surface is irregular with a rather nondescript internal structure and some local channel development.



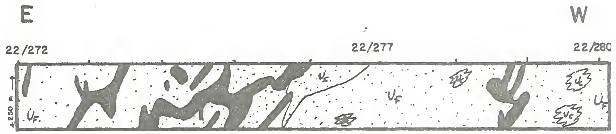



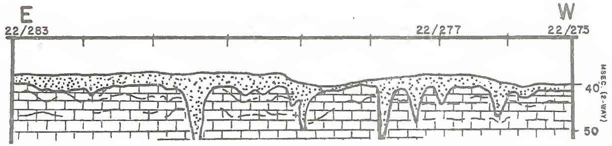
Station 2317 - located 300 m NW of s.p. 22/277, depth 28 m

SSS - texture : predominantly weak with diffuse patches of coarser material. Limestone highs outcrop between s.p. 22/273 and 22/276 and also at s.p. 22/279

bedforms : large low-relief swells evident on PDR profile at:
s.p. 22/273-273.7 (210 m x 1.2 m) asymmetrical NE
s.p. 22/275.9-278.1 (670 m x 2.0 m) " "
s.p. 22/278.8-287.4 (2600 m x 2.6 m) " "

Subbottom profiles - About 2 m of unconsolidated sediments veneer a level limestone plain (locally karstified). These karst features appear to be dolines that are filled and overlain by thin (<3 msec) sediment lenses.



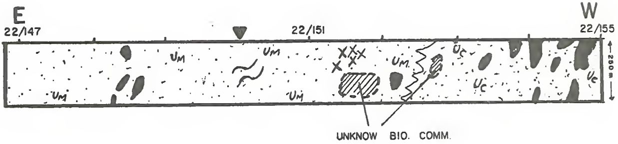



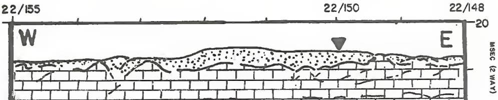
Station 2318 - located 600 m NW of s.p. 22/150, depth 20 m

SSS - texture : moderate reflectivity material grading into coarser sediment to the west at s.p. 22/152-153

bedforms : large scale sand waves at s.p. 22/150 and reticulate megaripples at s.p. 22/151
Unknown epibenthic community is present on unconsolidated substrate; patchy at s.p. 22/151.5 but more dense at 152.5.
s.p. 147.3-148.3 (300 m x 1 m) symmetrical
s.p. 148.7-152.2 (1070 m x 2 m) asymmetrical SW

Subbottom profiles - 2 to 3 m of unconsolidated sediments overlay an irregular limestone surface. This lense thins to one meter or less on the east and to a feather edge on the west, where outcrops appear to be more common. The sediments to the west may be a coarse lag overlying the limestone. The lens appears to have been periodically subjected to significant hydrodynamic activity as evidenced by development of large scale bedforms.



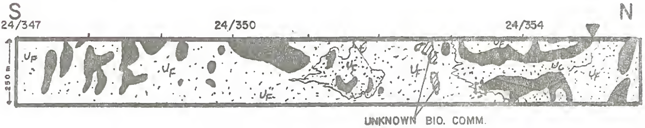



Station 2419 - located 760 m E of s.p. 25/1, or 900 m E of s.p. 24/355, depth 8.5 m

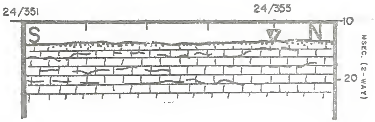
SSS - texture : extremely variable, weak to strong (or lithified). Note the differences between lines 24 and 25. Line 24 is predominantly characterized by finer sediment while on 25 the sediment is relatively coarse

bedforms : long wave length, low relief swells between s.p. 25/7.7 and 9.2 (450 m x 1.2 m relief). This bedform is topped by dense "fuzzy" patches probably caused by epibenthic community of unknown character

Subbottom profiles - The section shown is at the end of profile 24. Unconsolidated sediments apparently exist as a very thin (less than pulse width) discontinuous veneer over a relatively flat limestone surface. Reflections within the basal unit are not diagnostic, although further south (on line 24), some karst signatures were noted. Because of the very thin unconsolidated unit, it is extremely difficult to pick any shallow structural indicators of outcrops which would verify the apparent outcrop signatures noted on SSS records.



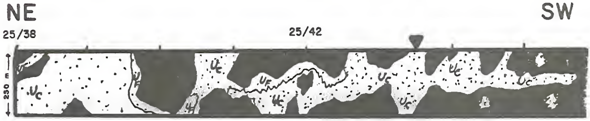


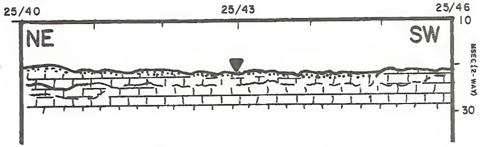


Station 2420 - located 900 m SE of s.p. 24/43, depth 15 m

SSS - texture : rugged (rocky?) very high reflectivity bottom with a thin discontinuous veneer of predominantly high reflectivity material; the latter is less than one meter thick and is usually confined to solution features on the rugged weathered limestone surface.

Subbottom profiles - very little penetration. Subbottom reflectors generally few, weak, irregular and discontinuous. Unconsolidated sediments, where present, are too thin to be defined on boomer records. The 3.5 kHz records were of poor quality in shallow water due to ringing.



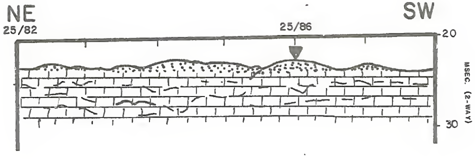
Station 2421 - located about 1200 m SE of s.p. 25/86 m, depth 18 m

SSS - texture : Variable, weak to strong refelctivity bottom. Types are intermixed, often with diffuse boundaries. Patches of finer sediment correspond to large bedforms.

bedforms : Low-relief, long wavelength swells are abundant:
s.p. 25/83.7-85.45 (530 m x 2 m relief) asymmetrical NE
s.p. 25/85.45/86.55 (330 m x 1.8 m relief) symmetrical
s.p. 25/87.6-89.9 (275 x 2 m relief) symmetrical
s.p. 25/89.9-91.15 (380 x 1.6 m relief) symmetrical

Smaller scale bedforms are represented by reticulate patterns at s.p. 25/86 on the east flank of the larger bedform. These may be lingoid megaripples suggesting relatively strong hydrodynamic activity.

Subbottom profiles - Unconsolidated veneer thicker than we noted on previous station (2419, 2420). Thin (~2 m thick) lenses were associated with larger bedform types. The boundary between sediments and bedrock is poorly defined on records due to thin units and/or lack of impedence contrast. Subbottom reflectors are irregular, weak and discontinuous.

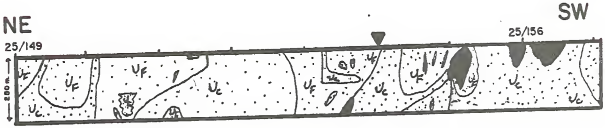



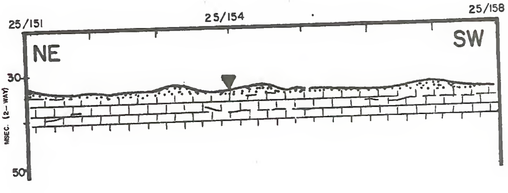
Station 2422 - located 600 m NW of s.p. 25/154, depth 25 m

SSS - texture : variable weak to strong (or hard)
Finer sediment patches correspond to slight rises on the seafloor. Troughs and flat bottom correspond to coarser sediment and occasional outcrops. Usually a gradation from weak to strong backscatter level is noted from top to bottom of the larger bedforms.

bedforms : major low relief long wave length swells noted at:
s.p. 25/149.8-151.2 (425 m x 1.6 m)
s.p. 25/152.4-153.5 (335 m x 1.2 m)
s.p. 25/156.5-157.8 (400 m x 1.6 m)
s.p. 25/158.8-160.5 (520 m x 1.6 m)

Subbottom profiles - little penetration; unconsolidated/rock interface is not well defined (see previous stations). Unconsolidated sediments appear to be confined to thin lenses on a smooth undissected rock surface.



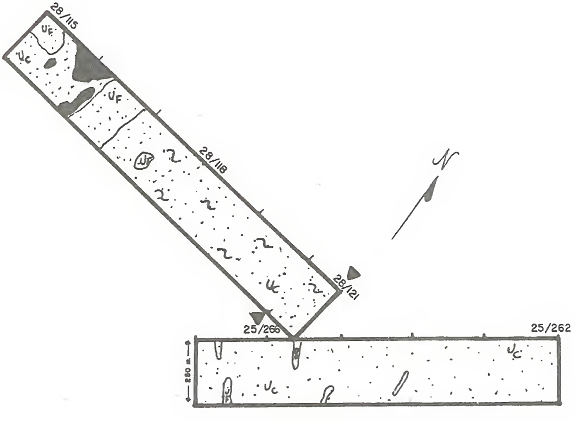



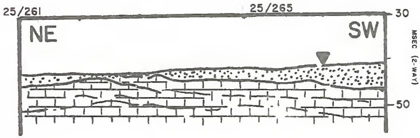
Station 2423 - located at s.p. 25/266 (or 28/121), depth 30 m

SSS - texture : primarily high reflectivity bottom with small patches of finer sediment - a small area of outcrop is apparent on line 28.

bedforms : essentially flat with ripples developed on coarser sediments on line 28 - no larger bedforms in the vicinity

Subbottom profiles - A thin, discontinuous veneer of unconsolidated sediment begins to thicken to the SW at s.p. 25/263. Subbottom reflections suggest that SW dipping upper rock strata are truncated at s.p. 262-263. Subbottom reflectors are relatively coherent and continuous in comparison to previous stations (i.e., Stations 2419-2422).



Station 2424 - located at s.p. 32/1, 32/244, 26/95 and 27/2; depth 30 m

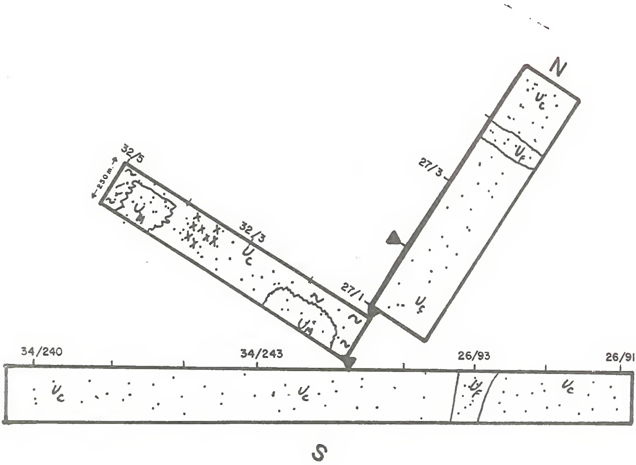
SSS - texture : Relatively uniform, moderate to strong backscatter levels. (Slight variations in gain settings at intersection of transects run days apart caused some records to appear darker than adjacent ones). Lower reflectivity material occurred in the troughs between the large bedforms.

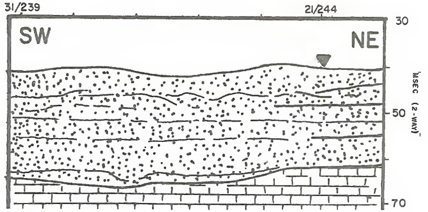
bedforms : low-relief, long wave length swells noted at:
s.p. 26/87-92.9 (1800 m x 314 m relief) asymmetrical NE
s.p. 27/2-7 (1500 m x 3.2 m relief) asymmetrical NE
s.p. 32/2-4.25 (690 x 2.8 m relief) symmetrical

Superimposed on the last bedform are ripples and reticulate megaripples (lingoid?). These smaller bedforms may be present on adjacent lines but are easily detected when the profile is subparallel to the trend of the crest.

Subbottom profile - Approximately 20 m of unconsolidated sediments overlying strong basal reflector. Upper unit exhibits no distinctive bedding or internal structure but lies on an irregular discontinuity surface. There appear to be three distinct, concordant sequences overlying the basal unit. These probably represent post-Miocene siliclastics derived from the coastal plain to the north. Numerous complex cut and fill structures are noted in the vicinity and deeply incised channels are present to the west.

Station 2424 - located at s.p. 32/1, 32/244, 26/95 and 27/2; depth 30 m



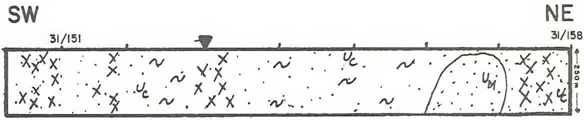



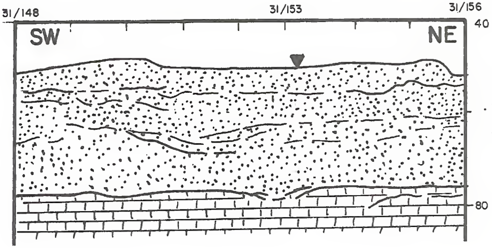
Station 2425 - located at s.p. 31/153, depth 37 m

SSS - texture : predominantly strong backscatter levels with one patch of finer (moderate) sediment occurring in a trough between large bedforms.

bedforms : Considerable evidence is present indicating active bottom processes. Symmetrical small scale ripples and reticulate megaripples (lingoid?) present. Large, low-relief, long wave length swells occur at:
s.p. 150-155.6 (1700 m x 2.4 m) asymetrical NE
s.p. 156-161 (1680 m x 2.4 m) irregular in profile

Subbottom profiles - 20-25 m of unconsolidated sediment overly the basal surface. Unconsolidated material occurs in three major units bound by irregular reflectors (erosion surfaces?). Channels are developed in all units and in some instances (to the east) were incised into the basal surface. Internal structure is locally typified by numerous cut and fill structures usually associated with channel or point bar deposits.



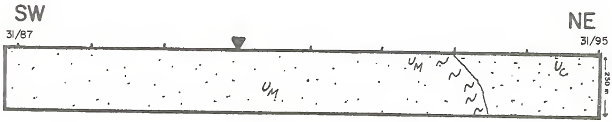



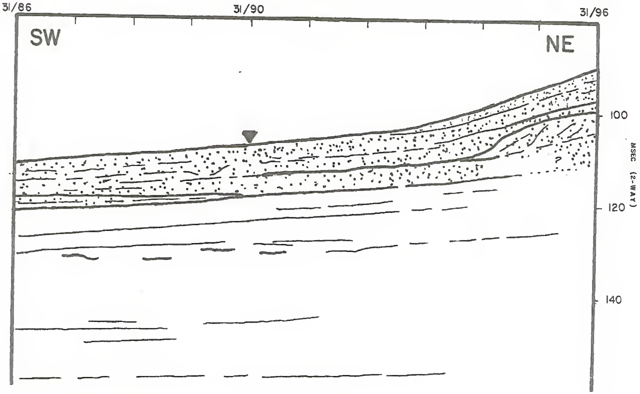
Station 2426 - located 3.4 km SW of s.p. 31/90, depth 86 m

SSS - texture : This station is projected to lie about 800 m seaward of the strong to moderate/weak transition at the base of the inner shelf break.

bedforms : At the textural transition (s.p. 31/93), ripple marks were noted suggesting contour currents may periodically be active near the base of the shelf break.

Subbottom profiles - This station lies seaward of an abrupt break in slope which is developed at the seaward terminus of the prograding Cape San Blas sand sheet. Internal structure of the rise suggests a complex of offlapping foreset bedding, erosional discontinuities and locally some reef-like structures. The coarser upper unit appears to pinch out at shot point 92.5 (on Boomer profile). Seaward the sediments become finer. Projection from well near the end of line 31 (see station 2427) suggest that total late-Pleistocene accumulation at s.p. 31/90 is in the order of 10 m.

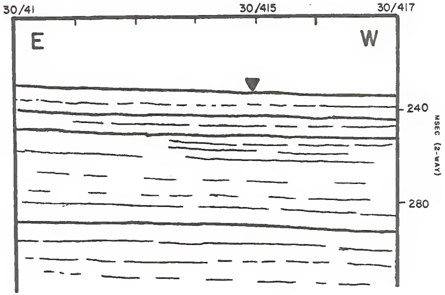


Station 2427 - located at s.p. 30/416, depth 174 m

SSS - texture : uniform, weak backscatter levels, no targets or bedforms detected

Subbottom profiles - A thick sequence of low impedance sediments characterizes this area. Nearby well control suggests deepest strong reflector (292 msec at 30/417) maybe the top of upper-Miocene strata. Second strong reflector (252 msec at s.p. 30/417) appears to approximate the base of the Pleistocene so total thickness of Pleistocene-Recent deposits at s.p. 30/417 is on the order of 14 m (assuming C=1.7-1.8 km/sec).



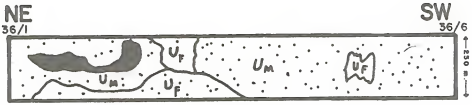
Station 2528 - located 20 m E of s.p. 36/2 (or s.p. 35/187), depth 38 m

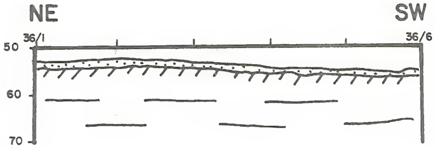
SSS - texture : predominantly moderate with small areas of weak backscatter levels

bedforms : Long wavelength, low-relief swells on PDR transect at:

s.p. 36/2.1-3.8 (510 m x 0.9 m) symmetrical
s.p. 36/3.8-5.8 (600 m x 0.6 m) symmetrical

Subbottom profiles - 3 to 4 m of unconsolidated sand separated by a poorly defined erosion surface from underlying, generally horizontal, sediments.



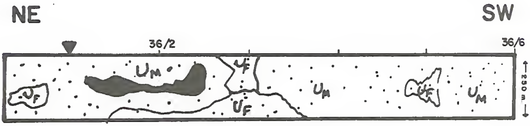
Station 2529 - located 2.8 km NW of s.p. 36/1 (or s.p. 35/190), depth 36-38 m

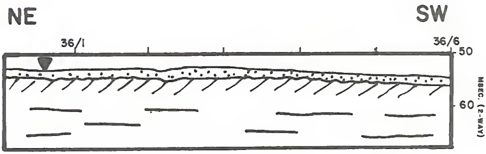
SSS - texture : predominantly moderate with small areas of weak backscatter levels

bedforms : Long wavelength, low-relief swells on PDR transect at:

s.p. 36/2.1-3.8 (510 m x 0.9 m) symmetrical
s.p. 36/3.8-5.8 (600 m x 0.6 m) symmetrical

Subbottom profiles - 3 to 4 m of unconsolidated sand separated by a poorly-defined erosion surface from underlying generally horizontal sediments



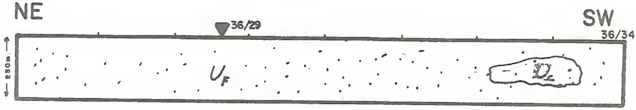
Station 2530 - located 380 m SE of s.p. 36/29, depth 38-42 m

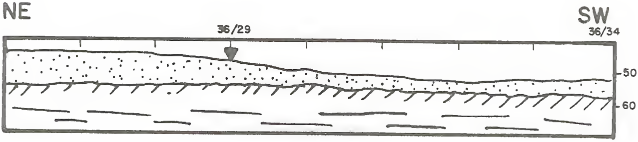
SSS - texture : nearly uniform moderate with some strong and weak back-scatter levels

bedforms : Long wavelength, low-relief swells on PDR transect at:

s.p. 36/23.5-27.6 (1250 x 1 m) symmetrical
s.p. 36/27.6-30.1 (770 x 1 m) symmetrical
s.p. 36/30.1-33.0 (940 x .5 m) symmetrical

Subbottom profiles - About 4 to 9 meters of predominantly medium sand overlies generally horizontal (partly-consolidated?) sequence underlying a poorly defined erosion surface.



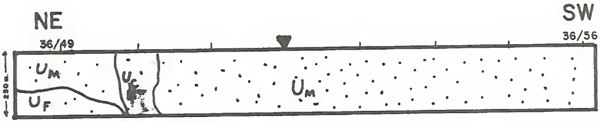



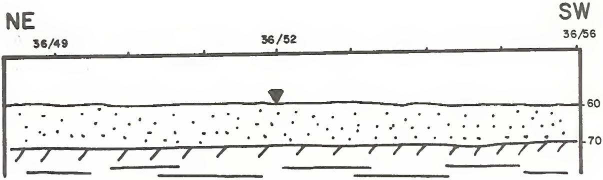
Station 2531 - located 490 m SE of s.p. 36/52, depth 44-46 m

SSS - texture : predominantly moderate with small areas of strong and weak backscatter levels

bedforms : gently sloping - about 2.4 m/km of bottom

Subbottom profiles - About 6 to 7 meters of mostly medium sand, overlies generally horizontally, partially consolidated(?) sediments beneath a buried erosion surface.



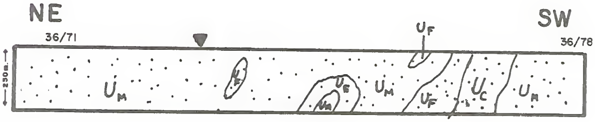
Station 2532 - located 420 m NW of s.p. 36/73, depth 49-54 m

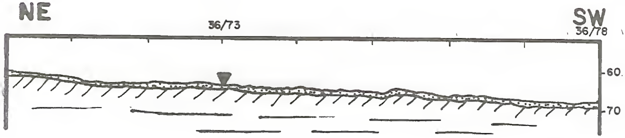
SSS - texture : predominantly moderate with small areas of strong and weak backscatter levels

bedforms : Very low amplitude, long wavelength sandwaves present at:

s.p. 36/72.2-73.2 (280 m x 0.5 m) symmetrical
s.p. 36/73.2-75.0 (570 m x 0.8 m) symmetrical
s.p. 36/75.0-75.8 (240 m x 0.8 m) asymmetrical
s.p. 36/75.8-77.0 (400 m x 0.9 m) symmetrical

Subbottom profiles - About 3 to 4 meters of unconsolidated medium(?) sand overlies generally horizontal sediments beneath a buried erosion surface.



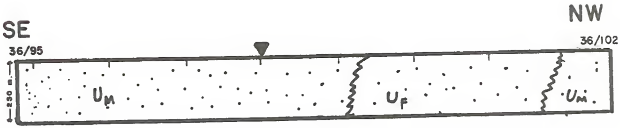



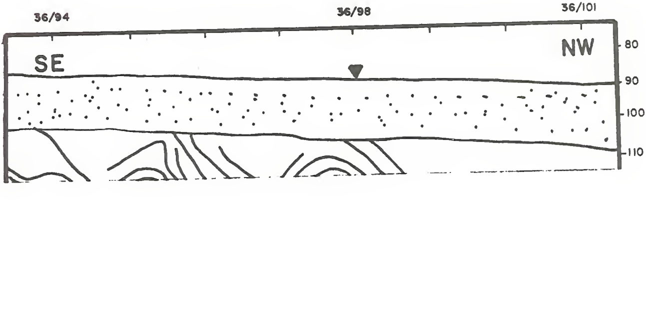
Station 2533 - located 160 m SE of s.p. 36/98, depth 66-70 m

SSS - texture : predominantly moderate with small area of weak backscatter

bedforms : no detectable bedforms. The bottom is nearly flat, sloping SW at about 1.2 m/kilometer

Subbottom profiles - About 8 m of unconsolidated fine-sediment overlie steeply dipping sediments which contain slump structures.



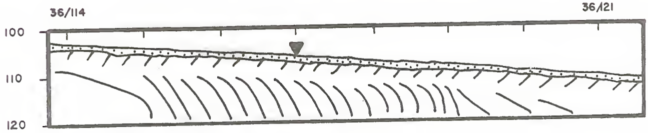



Station 2534 - located 1.1 km S of s.p. 36/117, depth 78 m - 85 m

SSS - texture : uniform, medium, backscater level

bedforms : no detectable bedforms, bottom sloping SE at 3.6 m/km

Subbottom profiles - About 7 m of unconsolidated fine sediment overlies at least 25 m of foreset beds dipping steeply to the SW.

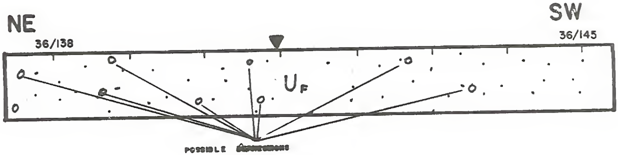


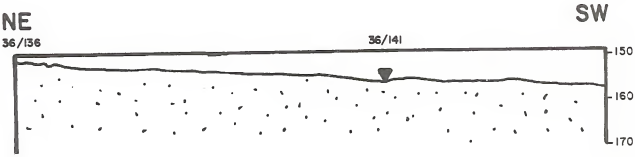
Station 2535 - located 20 m E of s.p. 36/141, depth 112-118 m

SSS - texture : weak backscatter level. Bottom covered with small targets appearing to be holes 5-10 m in diameter

bedforms : undetectable bedforms. Bottom sloping SSW at 2 m/km

Subbottom profiles - Thinly layered, fine(?) unconsolidated sediments dipping gently southwestward.



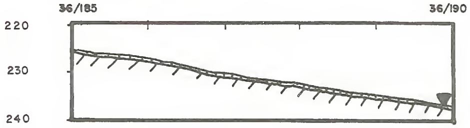



Station 2536 - located 290 m S of s.p. 36/190, depth 168-177 m

SSS - texture : weak backscatter level, uniform

bedforms : no detectable bedforms. Bottom appears smooth, sloping SSW at 5.9 m/km

Subbottom profiles - Thinly layered unconsolidated sediments dipping to SW.

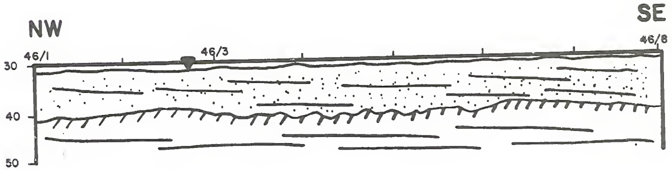


Station 2637 - located 700 m E of s.p. 46/3, depth 20-22 m

SSS - texture : weak backscatter levels, uniform

bedforms : flat bottom covered with small ripple marks. Gently sloping SSE at 0.57 m/km

Subbottom profiles - About 6 m of layered, unconsolidated fine sand(?) veneering a level sedimentary surface, which is probably partially consolidated. An erosion surface separates the surface unconsolidated layer from the underlying sediments, which are generally dipping to the southeast.



Station 2638 - located 300 m E of s.p. 46/45, depth 24-26 m

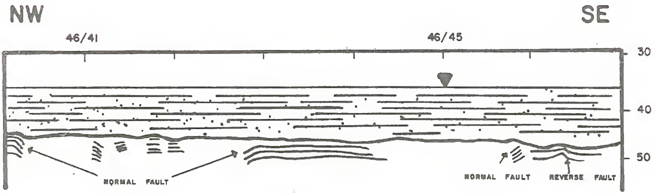
SSS - texture : uniform, weak backscatter level. Targets showing strong backscatter which may be bottom dwelling organisms are present in the vicinity at:

s.p. 46/35.6 (8 m diameter)
s.p. 46/37.9 (12 m diameter)

bedforms : none discernable. Smooth bottom with 0.52 m/km slope.

Subbottom profiles - About 8 m of thinly-layered, unconsolidated fine sand(?) overlies a buried erosion surface developed on nearly horizontal, probably partially consolidated sediments. Faulting (shallow) in the underlying sediments from:

| | |
|---|---|
| 46/40.2-43.0 | Normal faults. |
| 46/46.0 | Normal fault. |
| 46/46.4 | Possible reverse fault. |

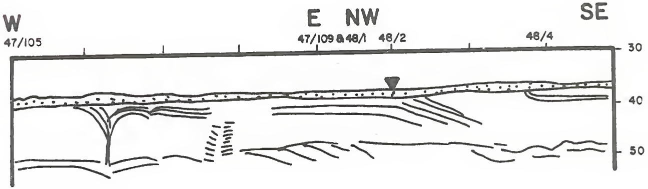


Station 2639 - located 950 m NE of s.p. 48/2, depth 32 m

SSS - texture : uniform, weak backscatter level

bedforms : irregular topography. PDR malfunction for s.p. 48/1-16

Subbottom profiles - About 3 meters of unconsolidated sediments overlie an erosion surface developed on faulted, nearly flat-lying to highly distorted sediment.



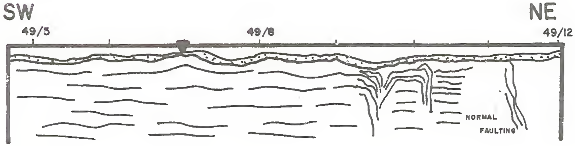
Station 2640 - located 1.4 km N of s.p. 49/7, depth 37-39 meters

SSS - texture : predominantly weak backscatter levels, with moderate to strong levels to the SW in wide zones perpendicular to the track, mostly between s.p. 49/2 and 49/5

bedforms : irregular hummocky topgraphy. Several smooth flat to irregular bedforms:

s.p. 49/2.0-4.5 flat relatively smooth surface
s.p. 49/4.5-7.1 rough bottomed depression, 21 m deep
s.p. 49/7.2-9.7 hummocky topography with a relief of 2.2 m
s.p. 49/9.7-12.0 nearly flat, somewhat rough bottom

Subbottom profiles - about 3 m of unconsolidated sediments overlie erosion surface developed on relatively flat-lying thickly bedded, probably partially consolidated sediments. Numerous normal faults begin at s.p. 49/9.5 and continue to the end of this track.

Station 2641 - located 640 m NE of s.p. 50/3, depth 35-39 m

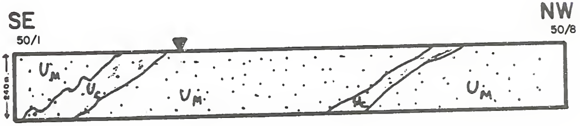
SSS - texture : predominantly moderate backscatter levels with two bands of strong backscatter.

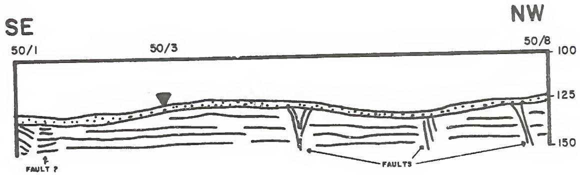
s.p. 50/1-2 (160 m wide)
s.p. 50/4.8-6.3 (60 m wide)

bedforms : bottom is covered with ripple marks with amplitudes too small to measure ($\leq$0.4 m) superimposed on a symmetrical bedforms and hummocky topography. In this area are two symmetrical "hills":

s.p. 50/1.7-5.4 (1160 m x 3.5 m) symmetrical
s.p. 50/5.4-12.6 (2100 m x 4.8 m) symmetrical

Subbottom profiles - About 2.5 to 4.5 m of unconsolidated sediments overlie an erosion surface beneath which relatively thick layers of generally flat-lying, partially consolidated(?) sediments have undergone faulting.



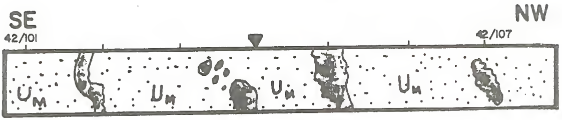
Station 2642 - located 630 m NE of s.p. 42/104, depth 35-39 m

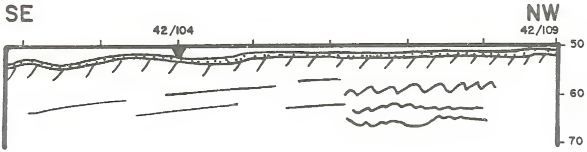
SSS - texture : predominantly moderate backscatter with a few areas of strong backscatter

bedforms : flat to hummocky topography

s.p. 42/99.0-104.6 hummocky topography, hummocks averaging about 300 m long by 2 m high
s.p. 42/104.6-106.6 nearly flat, somewhat rough bottom
s.p. 42/106.6-109.0 nearly flat, but relief up to 0.4 m

Subbottom profiles - About 3 m of unconsolidated sediment overlies a buried erosion surface underlain by horizontal to steeply dipping (partially consolidated?) sediments.



Station 2643 - located 1.0 km NE of s.p.42/47, depth 68-72 m

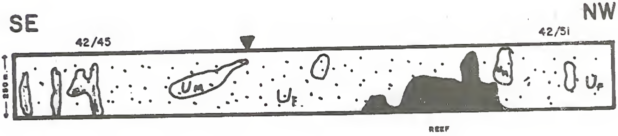
SSS - texture : predominantly weak (with few areas of moderate and strong) backscatter. A partially buried reef crops out between s.p. 42/48.7-50.6

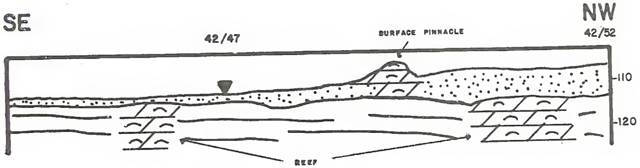
bedforms : flat, featureless bottom except for a pinnacle at:

s.p. 42/48.7-49.2 2.5 m relief

Subbottom profiles - 3 to 5 m of unconsolidated predominantly fine sand(?) overlies an erosion surface beneath which lies horizontal to steeply dipping beds.

s.p. 42/45.8-46.2
s.p. 42/47.0 to 47.9
s.p. 42/50.2 to 51.7



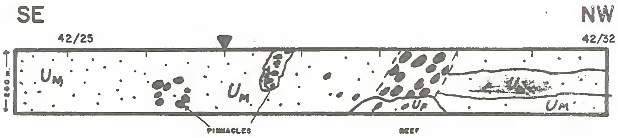
Station 2644 - located 1.9 km N of s.p. 42/27, depth 69-76 m

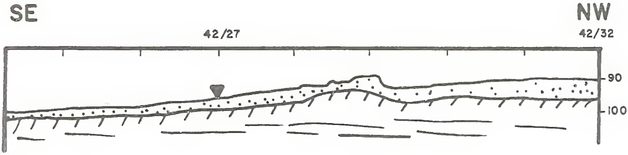
SSS - texture : predominantly moderate backscatter level with small areas of weak and strong. Very small pinnacles crop out from s.p. 42/22-23.7, 26.2, 26.5, 27.6 and s.p. 28.3-30.4. A reef zone about 150 meters wide is between s.p. 42/28.9-30.4, but appears to be almost completely buried.

bedforms : nearly flat, smooth bottom, except for partially buried reef at:

s.p. 42/27.5-28.9 2.4 m relief; symmetrical

Subbottom profiles - About 3 m of unconsolidated sediment overlies a buried erosion surface developed on probable semi-consolidated sediments.



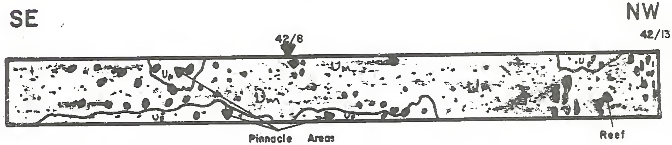
Station 2645 - located 2.7 km NE of s.p. 42/8, depth 92-131 m

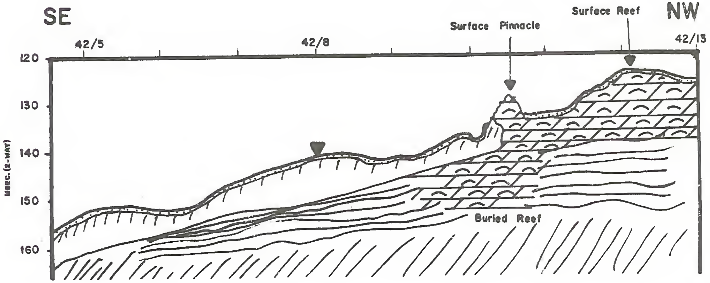
SSS - texture : predominantly moderate backscatter level with some weak areas. Numerous reef pinnacles crop out between s.p. 42/4.9-10, with large partially buried reef beginning at s.p. 42/11.6

bedforms : hummocky topography with one pinnacle reef

| | |
|---|---|
| s.p. 42/5.4-6.6 | Depression 3.5 m deep; symmetrical |
| s.p. 42/8.0-9.8 | Depression 2.5 m deep, nearly symmetrical |
| s.p. 42/9.8-10.1 | Depression 2.0 m deep, symmetrical |
| s.p. 42/10.1-10.4 | Pinnacle 3.5 m relief |
| s.p. 42/11.2-12.4 | Reef 3.5 m relief |

Subbottom profiles - unconsolidated sediments varying between 3 and 7 m overlie a buried erosion surface underlain by probably partially consolidated horizontal to steeply dipping sediments.



# Chapter 8 - SUMMARY

## 8.0 Introduction

This report of the results of the 1975 MAFLA-OCS geophysical investigation is based primarily on new information from three principal sources:

1) Approximately 3700 km of primary data from analog high - resolution geophysical profiles collected during the 1975 reconnaissance of the northern and peninsular shelves (including PDR, SSS and subbottom profiles).

2) Approximately 4700 km of primary data from analog high-resolution geophysical profiles from the peninsular shelf (subbottom profiles only).

3) Available NOS bathymetric maps

Chapters 1 through 6 of the report synthesize these data with previously published investigations to provide a framework from which to extropolate point data from other disciplines to regional mapping problems such as the bilithologic map series. This framework also provides a uniform data base applicable to evaluation of the design of the current benthic sampling program and future bottom sampling strategies for geophysical, geological and biological investigations. To facilitate these applications, some emphasis has been placed on providing an outling of the interpretive process used to reduce detailed geophysical data into a format applicable to regional mapping problems. Hopefully, this will increase the utility of the interpreted information by allowing investigators unfamiliar with high-resolution acoustic profiling technique to apply these data to problems in their own disciplines with greater confidence.

Interpreted profiling data is also presented in more detailed format in Chapter 7, the Station Atlas. The Station Atlas provides brief resumes of the geophysical characteristics of the 1975 box-core sample localities. These

descriptions have obvious direct applications as they allow evaluation of point data within the context of the local geologic setting. The balance of this summary consists of a running commentary covering specific points for re-emphasis and in many cases, may be of particular significance to interdisciplinary interpretation of data that have resulted from the MAFLA bottom sampling program. In addition, data summarized on the bedform maps are applicable to physical oceanographic studies concerned with seafloor response to hydrodynamic forces. These points are arranged in approximately the same order in which they are found in the main text for ease of back-reference to specific details.

Recommendations for additional investigations are found at the end of this chapter.

## 8.1 Bathymetry

The new NOS compilation of bathymetric data on the MAFLA shelf is a valuable contribution to understanding shelf processes. A number of smaller scale trends can be seen that were not apparent on previous maps. Unfortunately, missing sheets result in large data gaps on the peninsular platform that severly limited possible applications in this study.

The additional detail in some areas did allow projection of coral-algal ridge trends and delineation of other possible smaller coral-algal capped prominances west of the Florida Middle Ground reefs.

Major relief features present in the shelf are the relict spur-like ridges at the shelf break and on the outer shelf and the Florida Middle Ground reef complex. The internal structure of these features is summarized later in this section.

One unusual type of bathymetric anomaly was present on many of the NOS maps of the peninsular shelf. These are the elongate, east west striking

notches and offsets which trend normal to the bathymetry. All have the same strike and some, especially those at 28°30'N, are reflected far to the west as offsets in the face of the west Florida escarpment. Although the origin of these "notches" is unknown, their persistence across the shelf to the slope and their unusual linearity suggest the possibility of a common structural origin.

Additional bathymetric control would be necessary to detail the morphology of the Florida Middle Ground reef complex and other "hard-banks" and pinnacles of the MAFLA shelf.

8.2 Shallow Structure and Post-Miocene Sedimentary Framework

Information available from high-resolution subbottom profiling operations conducted on the MAFLA shelf outline major trends of a number of near-surface geologic hazards including faulting, slumping and karstification. In addition, when augmented with side-scan sonar data, regional trends of certain types of late-Quaternary carbonate buildups can be used to predict areas where "hard" substrate resulting from such buildups is more likely to be present. The same combination of data provides the basis for identification of outcrops; especially outcrops that have resulted from some apparent structural control.

Post-Miocene sedimentary units of the northern shelf, from Cape San Blas to Pensacola, are generally thick and dip gently seaward. A well developed erosion surface separates the upper 2-10 m of unconsolidated Holocene sands from underlying, older, more indurated sediments. Several buried stream channels were noted and welldeveloped foreset and topset beds occur close to the shelf break around DeSoto Canyon. High resolution profiles did not completely penetrate the thick post-Miocene section on the northern shelf west of Cape San Blas.

Faulting occurs near the middle of the northern shelf west of Panama City, but is not extensive. Well developed normal faults occur over a large portion of the shelf between Pensacola, Florida and Mobile Bay, Alabama. No unequivocal evidence for faulting was noted on the peninsular shelf.

Unidentified structures, that appear to be the result of salt plug intrusion, are found in the area immediately south of Mobile Bay. A filled depression which may be an extension of the Mobile Graben was encountered southwest of Mobile Bay.

The post-Miocene development of the peninsular shelf has been strongly influenced by the Middle Ground Arch. This structure has been the dominant positive element of the shelf throughout the Neogene and it has provided a barrier to influx of clastics onto the carbonate platform to the south. Post-Miocene stratigraphic units are generally very thin or absent over the eastern portion of this structural element. To the west, the relatively thick Plio-Pleistocene units also thin over the axis of the arch.

Landward of the shelf break most seismic sequences terminate. Shelf margin skeletal buildups dominate upper-Pleistocene strata between the 50 and 180 m isobaths, with little evidence of hydrodynamic types present seaward of 120 m. Upper Pleistocene units are generally more than 10 msec thick south of the trend of the arch and increase to about 40 msec thickness at the southern end of the study area. Upper Pleistocene (post-$A_2$) organic buildups are confined to a relatively narrow zone north of 28°N. This zone broadens considerably to the south resulting in development of a second break in slope on the outer shelf.

On the inner peninsular shelf the most prominent structures are the filled negative anomalies resulting from karst, stream and valley development.

Four major karst trends were mapped. Two of these, which are believed to indicate concentrations of dolines, are confined to the Big Bend region. The other two trends are believed to be "karren" surfaces and their relationship to breaks in slope suggest they may have resulted from locally high flux of ground water during previous sea level regressions. The majority of karst features occurred in belts which trend sub-parallel to the bathymetry and were almost invariably buried under a cover of unconsolidated sediments.

The inner shelf, between Tampa Bay and Charlotte Harbor is characterized by large filled channel and valley complexes. At the northern end of this trend, west of Tampa Bay, is a well developed, deeply incised, filled valley complex thought to be analogous to the present embayments that are developed along the west coast of peninsular Florida.

Unstable bottom was noted on the upper peninsular slope at two localities. Evidence of slumping was also noted on the upper slope around DeSoto Canyon. The disturbed units on the peninsular slope occurred where Plio-Pleistocene strata were anomalously thick. Evidence from stratigraphic tests on the slope suggest that the sediments occurring in these thick fills commonly consist of "soupy" silty sands. It should be noted that slumping on the peninsular slope was associated with very low gradients (less than 1°).

The utility of understanding, in detail, the trends of carbonate buildups becomes apparent when attempting to accurately map the occurrence of hard bottom on a regional level. Abrupt breaks in slope, indicating low relief scarps, and large closed bathymetric highs on the outer shelf often mark localities where a consolidated substrate is present. However, many of the prominences noted on bathymetric maps of the area only indicate the presence of an organic buildup which underlies a thick cover of unconsolidated

sediment. In the majority of cases, prominences capped by hard substrate occur along definite trends as do the relict algal ridges at the shelf break.

Based on internal structure and morphology, prominent carbonate buildups were classified into three general categories: (1) large skeletal buildups-predominantly hydrodynamic rearrangement; (2) large skeletal buildups-predominantly organic proliferation in-place; and (3) small skeletal buildups-predominantly organic proliferation in-place. Most types are confined to the shelf break and outer shelf; the only major exception being the Florida Middle Ground reef comples.

The largest buildups on the peninsular shelf are the spur-like ridges present at the shelf break. The primary structure of these buildups is hydrodynamic, with in-place organic proliferation being dominant during the latter stages of development. South of 28°N other linear buildups are present, primarily between depths of 140 and 180 m. These are in-place organic types that have subsequently been blanketed by 10 to 20 msec of fine sediments. The most seaward of these structures are developed on top of "soft" strata. Side-scan sonar and subbottom profiler observations suggest that evidence for evolution on such substrate is present on the outer peninsular shelf. The proposed cycle is: colonization of small patches which ultimately evolve into pinnacles; coalescence of the pinnacles eventually results in a suitable "hard" substrate for continued development of large banks. Estimates of time required for these buildups to have evolved to their present proportions suggest they are probably pre-Wisconsin in age.

Small in-place organic buildups are represented by pinnacles and linear coral-algal ridges, both being most common on the outer shelf and at the shelf break. The most well developed pinnacles were observed around the

margins of DeSoto Canyon and on the outer peninsular shelf between 27°N and 28°N. The depth range (120-150 m) and isolation of the latter reef belt, in an area characterized by soft bottom, suggests that concentrations of bottom fish may be present. A similar pinnacle reef trend on the peninsular shelf south of the study area is designated as an important recreational and commercial fishing bank. Unlike the pinnacles indigenous to the shelf break, the trend mapped on the outer shelf occurs on a "soft" substrate and shows little tendency to be associated with positive morphological elements.

Landward of the shelf break, on the peninsular shelf, the only large skeletal buildup is the Florida Middle Ground reef complex. The structural fabric suggests that its present relief is dominated by in-place organic proliferation with karstification contributing to some of its secondary relief. The eastern ridge system is developed on the seaward margin of a carbonate terrace overlying Middle Ground Arch. The west ridge may have developed on a southward prograding spur-like ridge similar to those developed at the shelf break.

We were able to differentiate major reef fauna zonations on side-scan sonar profiles, suggesting the utility of applying such surveys to large scale quantitative mapping of epibenthic communities on the shelf. In this instance, after consultation with Dr. T. S. Hopkins (University of Alabama) we were able to differentiate between the fringing Millepora zone, Gorgonian Sponge flats and faunally impoverished areas of the reef crest. Future detailed investigations based on side-scan sonar profiles augmented with closed circuit television and dredge samples would be an efficient approach to characterization of other sonar signatures that are, at present, enigmatic.

8.3 Texture Maps

The SSS Texture maps (Figs. 26, 27 and 28) graphically illustrate the

distribution of lithotopes in the MAFLA-OCS study area. These maps summarize relative backscatter levels and hard bottom types observed on both SSS and profiler data on a regional level. For discussion purposes, the study area is subdivided into five major zones (I through V) based on the dominant acoustic character, degree of textural variability, and presence or absence of various types of hard bottom. In addition, a number of subordinate trends of local significance are noted. Major and subordinate trends are summarized on Figure 30 and acoustic-textural differences are diagrammatically shown on the corresponding ternary diagrams (Fig. 31).

Although the significance of descriptive acoustic-textural data based on relative reverberation can only be roughly assessed in the absence of "ground-truth", such data provide the only method by which one can observe the degree of textural variability and distribution of hard bottom at the reconnaissance level.

Comparison of acoustic-texture trends to published lithofacies trends and textural data from the box-cores suggested no major discrepancies when equating reverberation levels with textural size. In fact, our qualitative acoustic texture maps and Gould and Stewart's (1975) generalized texture maps of the central west Florida shelf show similar, although not exactly analogous, major zonations.

One important aspect of both shelves is the extreme textural variability noted landward of the shelf break. The sketches of analog records adjacent to box core sites in the Station Atlas (Chapter 7) exemplify the small-scale variability present in many areas. This has extremely important implications pertinent to the explanation of observed inter and intra seasonal variability which might be present in the results of geological, chemical and biological core analysis (e.g., seasonal effects cannot be separated from minor navigational error or vessel motion in areas of

textually variable bottom).

Because of the importance of hard bottom ecosystems to the economics of Gulf coast industries based on commercial and sport fishing, the distribution and characterization of indigenous biotopes should be assigned high priority for documentation by both mapping and sampling. Unfortunately, as Gould and Stewart (1955) point out, "because of a sampling density of 1 per 9 sq. mi. it is impossible to show boundaries between bare rock exposures and unconsolidated sediments. Therefore, the unconsolidated sediments are shown diagrammatically...as a continuous cover." The present MAFLA-OCS sampling program is considerably less dense (about 1 per 900 sq. mi.) and therefore any attempt at accurate protrayal of the distribution of hard bottom on the shelf from this data base in unrealistic. Sonar coverage can mitigate such difficulties by providing continuous data which, if dense enough, can be applied to quantitative mapping of the distribution of hard bottom types on a regional scale. If augmented by sampling based on observed differences in acoustic signatures and known depth/geographic ranges of specific biotopes then some semblance of documentation can be achieved.

Our observations suggest the major occurrence of hard bottom types on the MAFLA shelves to be coral-algal reefs and banks on the outer shelf and upper slope (areas commonly characterized by conventional investigations as soft "muddy" bottom). High concentrations of such targets south of 28°N on the peninsular platform suggest that hard bottom may be an ecologically significant lithotope on the deeper portions of the platform. Characterization of the MAFLA shelves requires initiation of greater effort directed at realistic assessment of the various types of hard bottom ecosystems present.

### 8.4 Bedform Maps

Side-scan sonar evidence of bedform development on the MAFLA shelf provides an indicator of the response of the seafloor to hydrodynamic forces. Inshore, giant and large scale bedforms indicate a complex interaction of waves and tides. The shoals off Cape San Blas may show the net effects of major storm passage. Small scale bedforms at the shelf break, at depths greater than 60 m, suggest that currents are present on the deep shelf. Contourite dunes between 100 and 130 m on the upper slope of the west Florida platform suggest a strong current flowing parallel to the bathymetry between 28 N and 29 N. Current magnitudes of 50-100 cm/sec are estimated to be necessary for formation of the majority of bedforms observed on the shelf. The forces generating these currents in order of importance are thought to be: storms, tides and possible incursions of the Loop Current onto the peninsular shelf.

Although the exact mechanism usually cannot be determined in a normal reconnaissance, sonar data can detect abnormal or "active" bottom and, consequently would be useful to delineate type areas for design of physical oceanographic investigations, particularly instrument siting.

### 8.5 Unidentified Targets

Eight types of "acoustic-problematica" were common on the peninsular part of the platform. Occurrences tended to be concentrated in two areas: the inner shelf at depths less than 25 m and the outer shelf and upper slope seaward of the shelf break.

The deepest zone contained the highest diversity and abundance of targets including large, rimmed, circular depressions (ca. 2 m x 30 m), large and small high reflectivity (hard?) "spots", linear clusters of high reflectivity targets and mottled bottom. The hard targets are believed to be relict concentrations of coarser skeletal debris (coral-algal?) and

probably provide a foundation for modern deep-water attached epibenthic invertebrates. The mottled bottom may be due to small scale bedforms (e.g., ripples below resolution of instrumentation) or a mixture of sediment types.

A variety of signatures occur at depths shallower than 25 m. In the Big Bend region two distinctive types are prominent and are thought to represent dense, living epibenthic communities. Another mottled bottom signature was common at shallower depths between Tampa Bay and Charlotte Harbor.

Follow-up investigations should be initiated to characterize these distinctive signatures, as many are believed to represent important biotopes that are not presently being studied.

## 8.6 Recommendations

For the most part, recommendations for additional study are dependent on projected lease activity.

Additional subbottom profiles are recommended where active leases are in proximity to areas identified as containing near surface faults, slumped strata and karst structures. These would include the faulted areas south of Mobile Bay and west of Panama City, Florida, the slumped strata adjacent to DeSoto Canyon and on the upper peninsular slope north of 27°N and the karst trends of the peninsular shelf, especially those which occur over the Middle Ground Arch landward of the 60 m isobath.

We also recommend expediting completion of the NOS bathymetric map series to eliminate the major data gaps off Charlotte Harbor, the outer peninsular shelf between 26°N and 28°N and seaward of Cape San Blas. These maps will be useful for identification and more accurate projection of trends of carbonate buildups which are applicable to prediction of areas where hard substrate is likely to occur.

It is believed that hard bottom areas of MAFLA are insufficiently documented to accurately assess the impact of environmental changes that might be induced by offshore petroleum exploration and development. This is especially true of the peninsular shelf where hard bottom is not restricted to a narrow zone along the shelf break. Again the priority assigned to areas to be documented should be dependent on lease activity.

The present emphasis of the epifauna and epifloral investigations is on the main relief features of the Florida Middle Ground reef complex. However, with respect to area, the southern extension of the east ridge is an important component of the reef complex and should be characterized, at least at the reconnaissance level, in future studies. Addition, more detailed, SSS surveys of the Florida Middle Ground complex could be designed so that ground truth data from existing dive/dredge stations could be extrapolated to a much larger area. This would entail a close survey net (preferably closer than one mile square) and modified SSS procedures allowing higher resolution of small targets yet to be documented by more than a few geophysical profiles. Hard bottom in this trend may constitute more than 10% of the total area where patch reefs occur in locally dense concentrations. Again, characterization at the reconnaissance level would be an appropriate first step.

The recommended approach for acquiring additional information on the hard-substrate areas of MAFLA would include simultaneous SSS and subbottom profiles data augmented by CCTV and an acoustic drag. Selected dredge hauls could be acquired where necessary (preferably during the same operations). This approach would also allow adequate ground truth for identification of most of the enigmatic sonar signatures which might be encountered.

A few textural trends believed to be of regional significance were not included in the 1975 box-core program. Although it was not possible to wait for a geophysical survey before starting the present benthic sampling program, this should not be used as an excuse to avoid expanding or redesigning the future sampling strategy in light of evidence now available.

REFERENCES

Allen, J. R. L. 1970. Physical Processes of Sedimentation. New York: American Elsevier, 248 pp.

American Association of Petroleum Geologists (AAPG) 1970. Bathymetric Maps, Eastern Continental Margin, U.S.A., sheet 3 - Northern Gulf of Mexico.

Antoine, J. W. 1965. Structural features under Continental Shelf of Florida panhandle revealed by seismic reflection measurements, (abs.) Geophysics 30 (6): 1228.

_______ 1972. Structure of the Gulf of Mexico, In: R. Rezak and V. J. Henry (eds.), Contributions on the Geological and Geophysical Oceanography of the Gulf of Mexico, Texas A&M Univ. Oceanogr. Stud., Houston, Texas: Gulf Publishing Co. 3: 1-34.

_______ and J. I. Ewing 1963. Seismic refraction measurements on the margins of the Gulf of Mexico. Jour. of Geophy. Res. 68 (7): 1975-1996.

_______ and J. C. Gilmore 1970. Geology of the Gulf of Mexico: Tectonophysics 10 (5-6): 477-492.

_______ and J. S. Harding 1965. Structure beneath continental shelf, northeastern Gulf of Mexico. Am. Assoc. Petrol. Geol. Bull. 49: 157-171.

_______ and T. E. Pyle 1970. Crustal studies of the Gulf of Mexico, Tectonophysics 10 (5-6): 477-494.

_______, W. R. Bryant and B. R. Jones 1967. Structural features of continental shelf, slope and scarp, northeastern Gulf of Mexico: Am. Assoc. Pet. Geol. Bull. 51 (2): 257-262.

_______, R. G. Martin, T. E. Pyle and W. R. Bryant 1974. Continental margins of the Gulf of Mexico: 683-693, In: C. A. Burk and C. L. Drake (eds.), The Geology of Continental Margins, New York: Springer-Verlag.

Applin, P. L. and E. R. Applin 1967. The Gulf series in the subsurface in northern Florida and southern Georgia: U.S. Geol. Survey Prof. Paper 524-G, 34 pp.

Back, R. M. 1972. Recent depositional environment of the Florida Middle Ground, unpubl. M.S. thesis, Dept. of Ocy., Fla. State Univ., Tallahassee, Florida.

Ballard, R. D. and E. Uchupi 1970. Morphology and Quarternary history of the continental shelf of the Gulf coast of the United States. Bull. Marine Sci. 20: 547-559.

Bergantino, R. H. 1971. Submarine regional geomorphology of the Gulf of Mexico. Bull. Geol. Soc. Am. 82: 741-752.

Braustein, J. 1970. Bibliography of Gulf coast geology. Gulf Coast Assoc. Geol. Soc., Spec. Publ. 1, 2: 1045 pp.

Brooks, H. K. 1962. Observations on the Florida Middle Ground (abs.). Geol. Soc. Am. Sp. Publ. 68: 65-66.

______ 1973. Geological Oceanography, In: J. I. Jones, et al. (eds.) A summary of knowledge of the Eastern Gulf of Mexico, p. IIE-1 - IIE-49, State Univ. Sys. of Florida Inst. of Oceanography, St. Petersburg, Florida.

Bryant, W. R., A. A. Meyerhoff, N. K. Brown, M. A. Furrer, T. E. Pyle, and J. W. Antoine 1969. Escarpments, reef trends and diapiric structures, Eastern Gulf of Mexico, Am. Assoc. Pet. Geol. Bull. 53 (12): 2506-2542.

Chen, C. A. 1965. The regional lithostratigraphic analysis of Paleocene and Eocene rocks of Florida. Florida Geol. Survey Bull. 45: 105 pp.

Curray, J. R. 1960. Sediments and history of the Holocene transgression, continental shelf, northwest Gulf of Mexico, 221-226, In: F. P. Shepard (ed.), Recent Sediments, northwest Gulf of Mexico. Am. Assoc. Pet. Geol. 394 pp.

Damuth, J. E. 1975. Echo character of the western equatorial Atlantic floor and its relationship to the dispersal and distribution of terrigenous sediments. Mar. Geol. 18: 17-45.

Emery, K. O. and E. Uchupi 1972. Western North Atlantic Ocean: topography, rocks, structure, water, life and sediments. Am. Assoc. Pet. Geol. Mem. 17, 532 pp.

Flemming, B. W. 1976. Side-scan sonar: a practical guide. Int. Hydrogr. Rev. LIII (1): 65-92.

Galloway, R. W. 1970. Coastal and shelf geomorphology and late Cenozoic sea levels. J. Geol. 78: 603-610.

Garrison, L. E. and R. G. Martin 1973. Geologic structures in the Gulf of Mexico basin. U.S. Geol. Survey Prof. Paper 773 85 pp.

Ginsburg, R. N. and N. P. James 1974. Holocene carbonate sediments of carbonate shelves, 137-155, In: C. A. Burk and C. L. Drake (eds.), The Geology of Continental Margins, New York: Springer-Verlag.

Goodell, H. G. and J. W. Yon 1960. The regional lithostratigraphy of the post-Eocene rocks of Florida 75-113, In: H. S. Puri (ed.) Late Cenozoic stratigraphy and sedimentation of Central Florida, Southeastern Geol. Soc. Guidebook 134 pp.

Gould, H. R. and R. H. Stewart 1955. Continental Terrace sediments in the northeastern Gulf of Mexico: Soc. Econ. Paleontologists and Mineralogists, Serial Pub. No. 3, Finding Ancient Shorelines 1-20.

Hadley, L. J. 1964. Wave-induced bottom currents in the Celtic Sea. Mar. Geol. 2: 192-206.

Halbouty, M. T. 1967. Salt domes - Gulf region, United States and Mexico: Houston, Texas: Gulf Pub. Co. 425 pp.

Harbison, R. N. 1967. DeSoto Canyon reveals salt trends. Oil Gas J. 65 (8): 124-128.

________ 1968. Geology of the DeSoto Canyon. J. Geophys. Res. 73 (16): 5175-5185.

Hardin, G. C., Jr. 1962. Notes on Cenozoic sedimentation in the Gulf coast geosyncline, U.S.A. In: Geology of the Gulf Coast and Central Texas and guidebook of excursions, Geol. Soc. America, 1962, Ann. Mtg.: Houston, Tex., Houston Geol. Soc. 1-15.

Heckel, P. H. 1974. Carbonate buildups in the geologic record: a review. In: L. F. LaPorte (ed.), Reefs in Time and Space, Soc. Econ. Paleontol. and Mineral Spec. Publ. 18: 90-154.

Heirtzler, J. R., L. H. Burckle and G. Peter 1966. Magnetic anomalies in the Gulf of Mexico. J. Geophys. Res. 71: 517-526.

Hollister, C. D., R. D. Flood, D. A. Johnson, P. Lonsdale and W. B. Southard 1974. Abyssal furrows and hyperbolic echo traces on the Bahama Outer ridge Geology 2 (8): 395-400.

Hull, J. P. D. 1962. Cretaceous Suwannee Strait, Georgia and Florida, Am. Assoc. Pet. Geol. Bull. 46: 118-122.

Jacobi, D., P. D. Rabinowitz and R. W. E. Embley 1975. Sediment waves on the Moroccan Continental rise. Mar. Geol. 19: M61-M67.

Jordan, C. L. 1973. The physical environment of the MAFLA shelf, In: J. I. Jones, R. E. Ring, M. O. Rinkel, R. E. Smith (eds.), p. IIA-1 - IIA-14, A summary of knowledge of the Eastern Gulf of Mexico, State Univ. System of Florida Inst. of Ocean. St. Petersburg, Florida.

Jordan, G. F. 1951. Continental slope off Apalachicola River, Florida. Am. Assoc. Pet. Geol. Bull. 35 (9): 1978-1993.

Jordan, G. F. 1952. Reef formation in the Gulf of Mexico off Apalachicola Bay, Florida. Geol. Soc. Am. Bull. 63: 741-744.

______ and H. G. Stewart, Jr. 1959. Continental slope off southwest Florida. Am. Assoc. Pet. Geol. Bull. 43: 974-991.

Kenyon, N. H. and A. H. Stride 1970. The tide swept continental shelf sediments between the Shetland Isles and France. Sedimentology 14: 159-173.

King, L. H. and B. Maclean 1970. Pockmarks on the Scotian shelf. Geol. Soc. Am. Bull. 81 (10): 3141-3148.

Kirkland, D. W. and J. E. Gerhard 1971. Jurassic salt, central Gulf of Mexico, and its temporal relation to circum-Gulf evaporites. Am. Assoc. Petrol. Geol. Bull. 55 (5): 680-686.

Krivoy, H. L. and T. E. Pyle 1972. Anomalous crust beneath west Florida shelf. Am. Assoc. Pet. Geol. Bull. 56: 107-113.

Lehner, P. 1969. Salt tectonics and Pleistocene stratigraphy on continental slope of northern Gulf of Mexico. Am. Assoc. Pet. Geol. Bull. 53 (12): 2431-2479.

Lewis, K. G. 1971. Slumping on a continental slope inclined at 1°-4°. Sedimentology 16: 97-110.

Logan, B. W., J. L. Harding, W. M. Ahr, J. D. Williams and R. G. Snead 1969. Carbonate sediments and reefs, Yucatan Shelf, Mexico. Am. Assoc. Pet. Geol. Mem. 11 1-196.

Loring, D. H., D. J. G. Nota, W. D. Chesterman and H. K. Wong 1970. Sedimentary environments on the Magdalen Shelf, southern Gulf of St. Lawrence. Mar. Geol. 8: 337-354.

Ludwick, J. C. 1964. Sediments in northeastern Gulf of Mexico. In: R. L. Miller (ed.), Papers in Marine Geology: Shepard Commemorative Volume. New York: MacMillan Co. 204-238.

______ and W. R. Walton 1957. Shelf edge calcareous prominences in northeastern Gulf of Mexico. Am. Assoc. Pet. Geol. Bull. 41: 2054-2101.

Martin, R. G. 1972. Structural features of the continental margin, northeastern Gulf of Mexico, U.S. Geol. Survey Prof. Paper 800-B B1-B8.

______ and J. E. Case 1975. Geophysical studies in the Gulf of Mexico. In: A. E. M. Nairn and F. G. Stehli (eds.) The Ocean Basins and Margins, vol. 3, The Gulf of Mexico and the Caribbean. New York: Plenum Press 65-106.

Matthews, R. K. 1974. Dynamic Stratigraphy. New Jersey: Prentice-Hall 370 pp.

McKinney, C. M. and C. D. Anderson 1964. Measurement of backscattering of sound from the ocean bottom. J. Acoust. Soc. Am. 36 (1): 158-163.

McLeroy, E. G. 1972. Measurement and correlation of acoustic reflection and sediment properties off Panama City, Florida: Naval Coastal Systems Laboratory, Panama City, Fla., Informal Rept. NCSL 112-72, 28 pp.

Meyerhoff, A. A. 1967. Future hydrocarbon provinces of Gulf of Mexico - Caribbean region. Gulf Coast Assoc. Geol. Socs. Trans. 17: 217-260.

Mitchum, R. M. 1976. Seismic Stratigraphic investigation of the west Florida slope: Gulf of Mexico. In: A. H. Bouma, et al. (eds.), Beyond the Shelf Break. Am. Assoc. Petr. Geol. Mar. Geol. Comm. Short Cource 2: I-1 - I-35.

Moe, M. A. 1970. Florida's fishing grounds, 2nd printing. St. Petersburg, Fla.: Great Outdoor Publ. Co. 80 pp.

Murray, G. E. 1961. Geology of the Atlantic and Gulf Coastal Provinces of North America. New York: Harper and Row 692 pp.

______ 1966. Salt structures of the Gulf of Mexico basin - a review. Am. Assoc. Pet. Geol. Bull. 50 (3), pt. i: 439-478.

Oglesby, W. F. 1965. Folio of South Florida basin - a preliminary study: Fla. Geol. Survey Map. Ser. 19, 3 pp.

Poag, C. W. and W. E. Sweet 1972. Claypile Bank, Texas continental shelf. In: R. Rezak and V. J. Henry (eds.) Contributions on the Geological and Geophysical Oceanography of the Gulf of Mexico. Texas A&M Univ. Oceanogr. Stud. Houston, Texas: Gulf Publ. Co. 3: 223-261.

Purdy, E. G. 1974. Reef configurations: cause and effect. In: L. F. Laporte (ed.) Reefs in Time and Space. Soc. Econ. Paleont. Mineral. Spec. Publ. 18: 9-76.

Puri, H. S., J. W. Yon and W. R. Oglesby 1967. Geology of Dixie and Gilchrist counties, Florida. Fla. Geol. Survey Bull. 49, 155 pp.

Pyle, T. E. and J. W. Antoine 1973. Structure of the West Florida Platform, Gulf of Mexico. Texas A&M Tech. Rept. 73-7-T, 168 pp.

____, R. C. Saunders and B. G. Buckley 1975. Bottom mapping and sampling to determine distribution of Florida red tide and other dinoflagellate cysts. Unpubl. rept. to Fla. Dept. Natural Resources Marine Research Lab., St. Petersburg, Fla., Oct. 1975, 71 pp.

Pyle, T. E., J. C. McCarthy, T. W. Neurauter, V. J. Henry and M. M. Ball 1976. Role of geophysics in biolithologic mapping, MAFLA continental shelf. Paper presented Fla. Acad. Sci. 40th Ann. Mtg., Fla. Scientist 39 (suppl 1).

Reineck, H. E. and I. B. Singh 1973. Depositional Sedimentary Environments. New York: Springer-Verlag 439 pp.

Revelle, R. and K. O. Emery 1957. Chemical erosion of beach rock and exposed reef rock. U.S. Geol. Sur. Prof. Pap. 260-T 699-709.

Rezak, R. and G. S. Edwards 1972. Carbonate sediments of the Gulf of Mexico. In: R. Rezak and V. J. Henry (eds.) Contributions on the Geological and Geophysical Oceanography of the Gulf of Mexico. Texas A&M Univ. Oceanogr. Stud. Houston, Texas: Gulf Publ. Co. 3: 263-280.

Rinkel, M. O. 1977. Physical Oceanography - Interdisciplinary environmental support data. Draft final report to Bureau of Land Management Contract No. 08550-CT5-30, prepared by SUSIO, St. Petersburg, Florida.

Schnable, J. E. and H. G. Goodell 1968. Pleistocene - Recent stratigraphy, evolution and development of the Apalachicola coast, Florida. Geol. Soc. of Am. Spec. Pap. 112, 72 pp.

Shepard, F. P. 1960. Gulf Coast Barriers 197-220. In: F. P. Shepard, F. B. Phleger and T. H. van Andel (eds.) Recent Sediments, Northwest Gulf of Mexico. Am. Assoc. Petr. Geol., Tulsa, Okla. 394 pp.

Smith, S. W. and D. W. Kinsey 1976. Calcium carbonate production, coral reef growth and sea level change. Science 194: 937-939.

Stanton, K. J. and I. Evans 1972. Recognition and interpretation of modern molluscan biofacies. In: R. Rezak and V. J. Henry (eds.) Contributions on the Geological and Geophysical Oceanography of the Gulf of Mexico. Texas A&M Univ. Oceanogr. Stud. Houston, Texas: Gulf Publ. Co. 3: 203-222.

Sternberg, R. W. 1972. Predicting initial motion and bedload transport of sediment particles in the shallow marine environments, 61-82. In: D. S. P. Swift, D. B. Duane and O. H. Pilkey (eds.) Shelf Sediment Transport: Process and Pattern. Stroudsburg, Penna.: Dowden, Hutchinson & Ross.

__________ and D. A. McManus 1972. Implications of sediment dispersal from long-term bottom-current measurements on the continental shelf of Washington. In: D. S. P. Swift, D. B. Duane and O. H. Pilkey (eds.) Shelf Sediment Transport: Process and Pattern. Stroudsburg, Penna.: Dowden, Hutchinson & Ross.

Storr, F. 1964. Ecology of the Gulf of Mexico commercial sponges and its relation to the fishery. Contribution 192 Marine Lab. Institute of Mar. Sci. Univ. of Miami. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. No. 466.

Stride, A. H. and W. D. Chesterman 1973. Sedimentation by non-tidal currents around northern Denmark. Marine Geology 15: M53-58.

Swift, D. J. P. 1973. Delaware shelf valley; estuary retreat path, not drowned river valley. Geol. Soc. Am. Bull. 84: 2743-2748.

_____, D. J. Stanley and J. R. Curray 1971. Relict sediments on continental shelves: a reconsideration. J. Geol. 79 (3): 322-345.

Tanner, W. F. 1961. Offshore shoals in areas of energy deficit. J. Sed. Petrol. 31: 87-95.

Taylor, J. L., D. L. Feigenbaum and M. L. Stursa 1973. Utilization of marine and coastal resources: Fisheries resources. In: J. I. Jones, et al. (eds.) A Summary of Knowledge of the Eastern Gulf of Mexico, IV-1 - IV-63. State Univ. Sys. of Florida Inst. Ocy., St. Petersburg, Fla.

Uchupi, E. 1975. Physiography of the Gulf of Mexico and Caribbean Sea: In: A. E. M. Nairn and F. G. Stehli (eds.) The Ocean Basins and Margins, v. 3. The Gulf of Mexico and the Caribbean. New York: Plenum Press 1-64.

Upshaw, C. F., W. B. Creath and F. L. Brooks 1966. Sediments and microfauna off the coasts of Mississippi and adjacent states. Miss. Geol. Econ. and Topogr. Surv. Bull. 106, 76 pp.

Vause, J. E. 1959. Underwater geology and analysis of recent sediments off the northwest Florida coast. J. Sediment Petrol. 29: 555-563.

Vernon, R. O. 1951 Geology of Citrus and Levy counties, Florida. Fla. Geol. Surv. Bull. 29, 256 pp.

Wilheim, O. and M. Ewing 1972. Geology and history of the Gulf of Mexico. Geol. Soc. Am. Bull. 83 (3): 575-600.

Winston, G. O. 1969. A deep glimpse of west Florida's platform. Oil Gas J. 67 (48): 128-133.

_____ 1976. Florida's Ocala Uplift is not an uplift. Am. Assoc. Pet. Geol. Bull. 60 (6): 992-994.

Wong, How-Kin and W. D. Chesterman 1968. Bottom backscattering near grazing incidence in shallow water. J. Acoust. Soc. Am. 44 (6): 1713-1718.

Yon, J. W. 1966. Geology of Jefferson County, Florida. Fla. Geol. Surv. Bull. 48: 119 pp.

___ and C. W. Hendry 1972. Suwannee limestone in Hernando and Pasco Counties, Florida. Fla. Geol. Surv. Bull. 54, part I, 42 pp.

SUMMARY OF DATA COLLECTION,

NAVIGATION AND CARTOGRAPHIC CONTROL

## NAVIGATION AND CARTOGRAPHY

DECCA Survey Systems, Inc. (DSSI) of Houston, Texas provided all navigation services and details can be found in their report to SUSIO, Hi-Fix Positioning Survey over Eastern Gulf of Mexico, Outer Continental Shelf and Slope (14 pp. plus charts), received October 15, 1975. This is included as Appendix I.

In summary, all positioning was accomplished with DSSI's Hi-Fix system operating in either range-range or hyperbolic mode. A Model 202A Decca Trisponder system was utilized for initial lane count acquisition. Pre-plots and post-plots of positions in Universal Transverse Mercator (UTM) coordinates were made on-board the survey vessel with an Autocarta X-Y plotter system. Corrected post-plot positions were tabulated and charted by DSSI for every 10th navigation point (10,000 ft.). Theoretical accuracy is stated in the DSSI report to be ±0.015 lanes (or ±2.5 m in range-range mode with a minimum 30° angle of intersection). DSSI also suggested that skywave or electrical storm interference could have resulted in an error of about ±0.2 lane (or ±35 m).

A copy of the tabulated UTM coordinates and corresponding latitude and longitude is included in Appendix B of this report. Figures 1, 2, and 3 are reduced copies of the track charts originally plotted by DSSI at a scale of 1:250,000. This map agrees with the preferred format outlined by Mr. D. A. Lipka (BLM, New Orleans, OCS Office) in his October 7, 1975 letter to Dr. T. E. Pyle (USF), i.e., Transverse Mercator projection; UTM grid, Clarke Spheroid of 1866.

Navigation and Cartography - continued

The DSSI plot also includes reference to latitude and longitude, based on North American Datum 1927. The choice of scale reflects the format which the National Ocean Survey is using for preparation of new bathymetric charts of the Gulf of Mexico.

It should be noted that all positions are referenced to 87° West longitude which is the central meridian of UTM Zone 16 (90° to 84°W). In other words, positions east of 84°W are in UTM Zone 17 but were not referenced to the central meridian of Zone 17 which is 81°W.

Appendix I

Abstracted from DSSI Report to SUSIO for BLM Cruise No. 16

*Hi-Fix Positioning Survey*

*over*

EASTERN GULF OF MEXICO

OUTER CONTINENTAL SHELF AND SLOPE

*for*

STATE UNIVERSITY SYSTEM OF FLORIDA

INSTITUTE OF OCEANOGRAPHY

ST. PETERSBURG, FLORIDA

*by*

*Decca Survey Systems, Inc.*

*8204 Westglen*

*Houston, Texas 77042*

## 1.0 INTRODUCTION

The State University System of Florida Institute of Oceanography (located at St. Petersburg, Florida) contracted with Decca Survey Systems, Inc., of Houston, Texas for 1) provision of an outfitted survey vessel to collect approximately 2000 miles of continuous high-resolution geophysical data for an environmental baseline monitoring survey of the MAFLA lease area and 2) provision of shore-based electronic position-fixing signals for the above survey vessel.

This report covers the position-fixing aspect of the survey, which began on 25 July and was completed on 17 August 1975.

## 1.1 INSTRUMENTATION

The *M/V DECCA PROFILER* was utilized as the survey vessel. This is a 115-foot twin-engine ship, equipped with certain geophysical instruments and equipments. Also installed was an Autocarta System for on-line preparation and processing of position-fixing data.

On board personnel furnished by Decca included a three-man navigation crew, one electronics engineer (to maintain Decca's on-board geophysical equipment), and a licensed vessel crew. Client's personnel operated the various geophysical instruments (both Client and Decca furnished). Specification sheets for the DSSI-furnished vessel and equipment are listed on Page 14 and follow thereafter.

## 1.2 AREA SURVEYED

The following report covers the position-fixing aspect of this environmental baseline survey. The survey was performed over part of the Outer Continental Shelf of the Eastern Gulf of Mexico. Specifically, the survey extended from Boca Grande Pass, Florida, west and north to Horn Island, Mississippi. Dip lines extended as much as 140 miles offshore in the southern portion of the area, to less than 35 miles off the Mississippi coastline. The area surveyed generally lies within the 200-meter depth contour of the Continental Shelf.

Electronic position-fixing for the survey vessel was provided by Decca's Hi-Fix System. Six chains were mobilized in Florida, all operating in the range-range mode. One established service chain, operating in the hyperbolic mode, was utilized over the westernmost portion of the survey (offshore Mississippi and Alabama).

The Hi-Fix shore station sites were connected by traverse either to 1) U. S. Coast & Geodetic Survey monuments, or to 2) Florida Department of Natural Resources monuments (established as part of the Florida Coastal Setback Program). (Coordinates for the latter monuments were furnished by phone from Mr. Harold Bean at the University of Florida, Gainsville.)

The various Hi-Fix station coordinates are listed in the Appendix.

## 2.1 SURVEY GRID

The survey tracklines cover two UTM zones in the Eastern Gulf of Mexico (Zones 17 and 16). In order to facilitate the handling of the navigation data, the trackline coordinates and Hi-Fix station coordinates were all converted into UTM in Feet coordinates for Zone 16 (Central Meridian 087° West). Trackline coordinates, as furnished by the Institute of Oceanography, were scaled from USC & GS Chart Number 1003 and converted on-board to UTM in Feet coordinates, for preplotting.

The final maps are likewise plotted on the same UTM in Feet grid, Zone 16. Geographical tick marks were added to enable direct matching with any other project maps. Grid coordinates, as tabulated in the postplot listing, also are referenced to this same UTM in Feet grid. Latitude and longitude are based on North American Datum 1927 (Clarke 1866 spheroid).

## 2.2 LANECOUNT ACQUISITION

The initial lanecount acquisition for the first chain (Gasparilla/St. Petersburg) was accomplished using the Trisponder 202A system with remote stations sited at Fort De Soto (FDNR Mark R-178) and on Anna Marie Key (USC & GS Mark Palm 3 RM1). Later lanecount transfer when moving from chain to chain, involved setting a positioning buoy, converting observed Hi-Fix range-range Pattern I and Pattern II readings of the buoy into the UTM X and Y coordinates with the Autocarta System. Next, using this data, the correct Pattern I and Pattern II readings were preplotted for the next chain to be used.

Lanecount acquisition for the Main Pass Hyperbolic Chain was accomplished by entering the known pattern readings of a range marker in the Mobile Bay ship channel into the Hi-Fix receivers while maneuvering close alongside.

## 2.3 ACCURACIES

The repeatable accuracy of a Trisponder 202A system (when having previously calibrated the Trisponder at ranges of similar distance) is on the order of ± ten feet.

The published, theoretical accuracy of a Decca Hi-Fix System working range-range mode and using a standard deviation of .015 lanes, incorporates an error of ± 2.6 meters or less within the 30° angle of intersection. The contractual accuracy is ± 50 feet repeatability under optimum signal conditions.

During periods of darkness, when skywave interference is possible, an allowance of ± 0.10 of a lane should be considered. Periods of electrical storms could result in signal interference and introduce a ± 0.20 of a lane ambiguity.

## 3.0 CHARTING

The Hi-Fix coordinates (for every tenth shot point) have been plotted on mylar charts, at a scale 1:250,000. Reduced, photographic copies are included as pages 10 through 12. Furthermore, a single chart on the scale of 1:1,000,000 covering the entire survey area, has been prepared, as per Institute of Oceanography instructions. Supplementing the charts, a tabular postplot listing was provided of each plotted fix (shot point). The listing included observed Hi-Fix coordinates, plus corresponding grid and geographic coordinates.

## 4.0 PERSONNEL

### Shipboard Survey Personnel

| | |
|---|---|
| James Gilmore | Electronics Engineer/Decca Party Chief |
| D. M. English | Hydrographic Surveyor (Field Assistant) |
| Marshall Terry | Hi-Fix Operator |
| Mike Pennington | Hi-Fix Operator |

### Shore Station Mobilization Personnel

| | |
|---|---|
| Robert Starck | Hi-Fix Chain Commander |
| Bill Orlang | Hi-Fix Technician |
| Walt Jackson | Hi-Fix Technician |

### Ship's Crew

| | |
|---|---|
| Harvey Spiller | Captain |
| Mike DuBois | Engineer |
| Sam Lucky | Mate |
| David Anderson | Deck Hand |
| Brady Shelton | Cook |
| Billy Brannan | Ordinary |

# APPENDIX A

## HI-FIX STATIONS

| No. | Hi-Fix Station | Location | Latitude | Longitude | Estimate of Station Site Accuracy |
|---|---|---|---|---|---|
| 1 | Gasparilla | Southern End of Gasparilla Island, Fla. | 26° 43' 03.377"N | 82° 15' 42.683"W | ± 2 feet |
| 2 | St. Petersburg | Pinellas Park, Florida | 27° 52' 12.147"N | 82° 42' 29.152"W | ±10 feet |
| 3 | Cedar Key | Cedar Key, Florida | 29° 08' 06.854"N | 83° 01' 56.556"W | ± 3 feet |
| 4 | Keaton Beach | Keaton Beach, Florida | 29° 49' 46.191"N | 83° 35' 42.852"W | ± 7 feet |
| 5 | Cape San Blas | Near Cape San Blas, Florida | 29° 41' 06.131"N | 85° 18' 23.708"W | ± 2 feet |
| 6 | Inlet Beach | Inlet Beach, Florida | 30° 17' 01.633"N | 86° 01' 51.768"W | ± 2 feet |
| 7 | Perdido Bay | On Florida-Alabama Line at Perdido Bay, Florida | 30° 16' 50.144"N | 87° 31' 05.867"W | ± 2 feet |
| 8 | Main Pass Slave #1 | Mississippi near Biloxi Bay | 30° 22' 21.677"N | 88° 14' 08.935"W | ±10 feet |
| 9 | Main Pass Slave #2 | In Mississippi Delta Near Venice, Louisiana | 29° 19' 58.372"N | 89° 24' 07.747"W | ±10 feet |
| 10 | Main Pass Master | In Louisiana near Lake Borgne | 30° 14' 24.133"N | 89° 25' 31.293"W | ±10 feet |

SUSIO/6 thru SUSIO/12
Intentionally blank

SUSIO/13

Appendix II

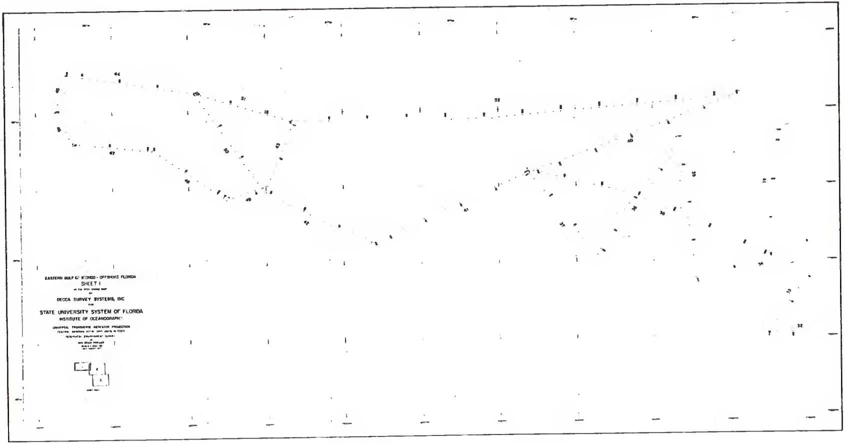



Figure 1. Track chart, geophysical profiles (sheet one).

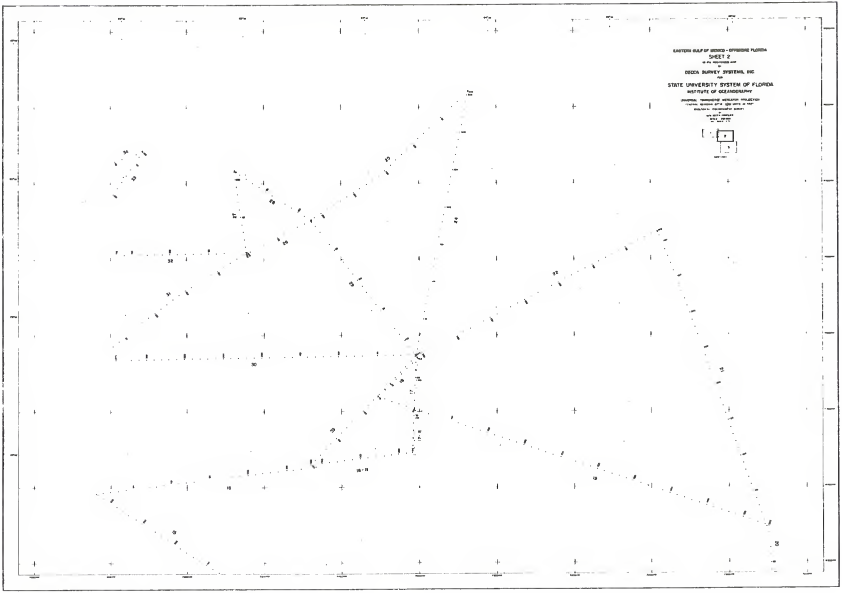



Figure 2. Track chart, geophysical profiles (sheet two).

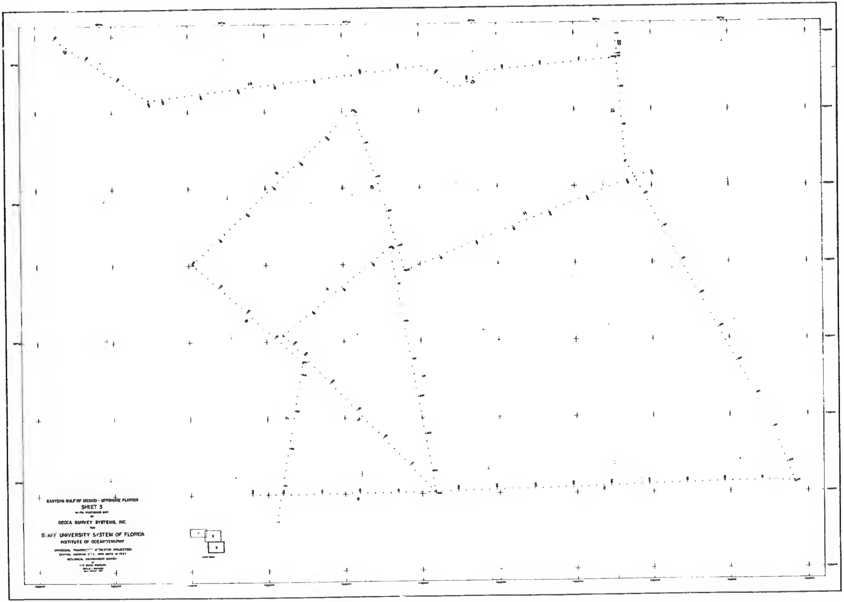



Figure 3. Track chart, geophysical profiles (sheet three).

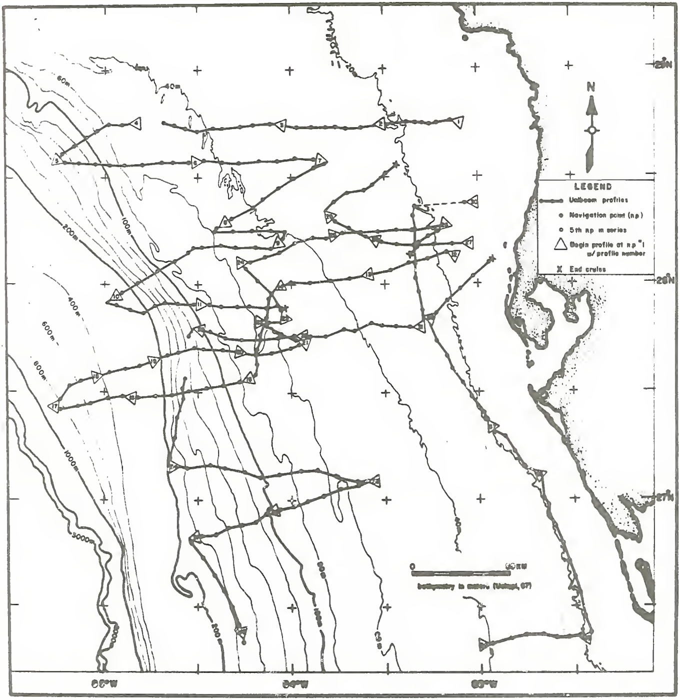



Figure 4. Historic uniboomer data evaluated in this project.

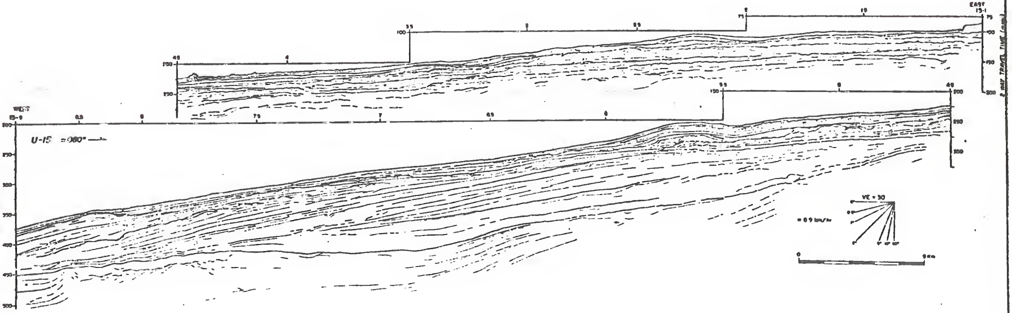



Figure 5. Line tracing of uniboom profile on outer west Florida shelf and upper slope. Various forms of organic skeletal buildups occur between 15/1 and 15/6. Slump structures are evident between 15/6.3 and 15/8.

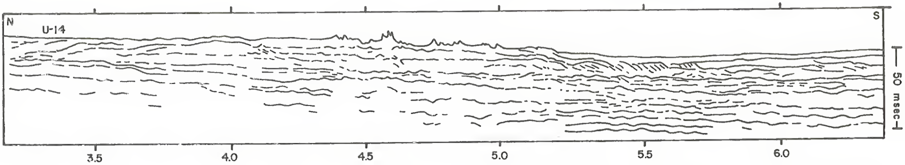



Figure 6. Line tracing of north - south section along the axis of a major ridge developed at the shelf break. Note the well developed pinnacles north of 5.0 and dipping beds south of 5.0. The latter is probably the result of southward migrating channel during the last regression. Overlying beds show no internal structures.

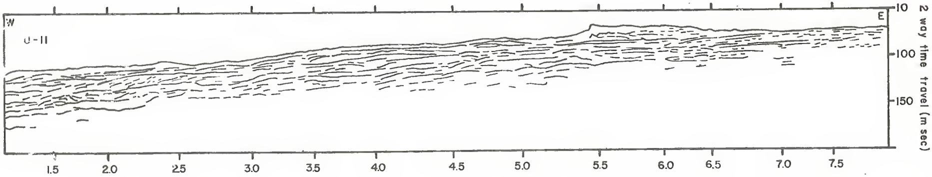



Figure 7. Section across ridge developed at the shelf break (see figure 6 for section along axis). The dominant structure between 5.5 and 6.5 is the feature reffered to as the "elbow" in the text. Seaward, a complex sequence of upper-Pleistocene banks and terraces are developed on two major erosion surfaces. A coral-algal ridge is located at 5.5.

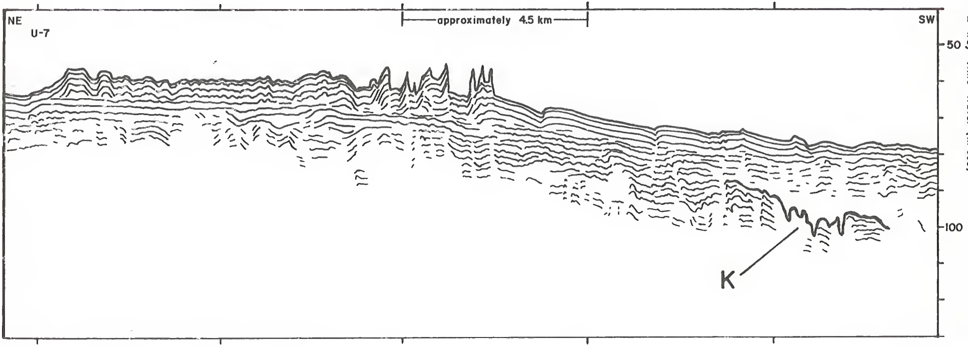



Figure 8. Uniboom record crossing southern trend of the Florida Middle Ground. Reef in this area is of lower relief and commonly shows pinnacle development. Note the extreme "karren-like" character of the subsurface horizon (K).

211

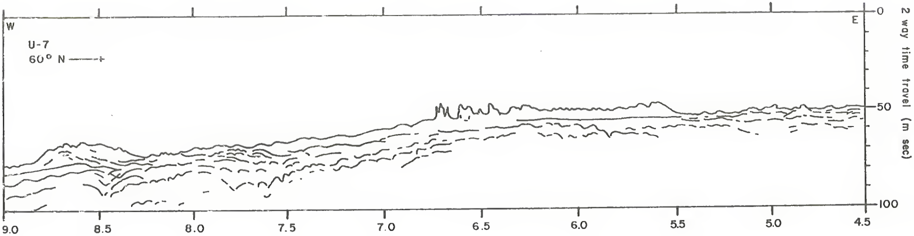



Figure 9a. Line tracing of uniboom profile crossing southern extension of the eastern ridge of the Florida Middle Ground reef complex. The "karren" surface is evident between 8.0 and 6.5.

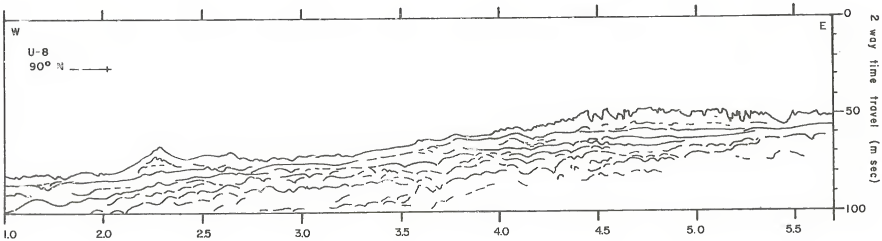
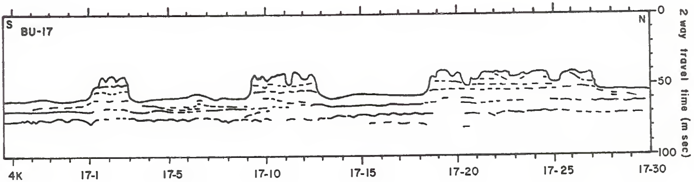



Figure 9b. Another crossing of the southern Middle Ground trend about 15 km south of the profile above. In this area, the reef between 4.0 and 5.7 is very dissected, suggesting karstification. "Karren" surface is evident between 3.5 and 5.7.



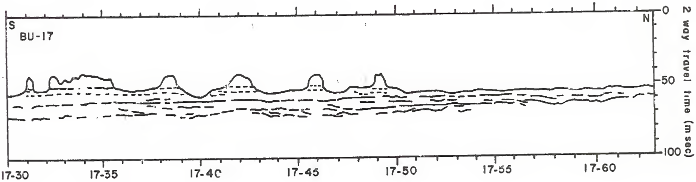




Figure 10. Line tracing of uniboom profile which runs along the margin of the western ridge of the Florida Middle Groung reef complex. Two internal reflectors are prominent within the reef structure. Strata underlying the reef thickens to the south.

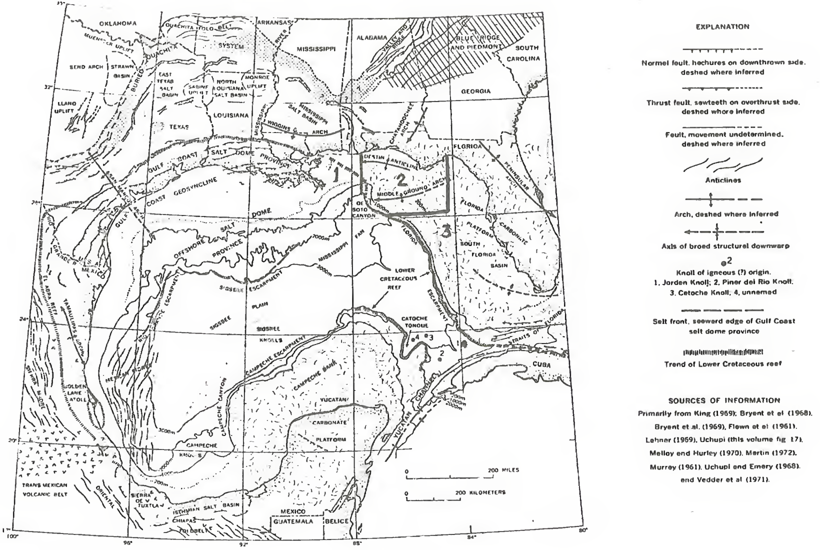



Figure 11. Tectonic sketgh map showing major structural trends and physiographic features in the Gulf of Mexico region, adapted from Garrison and Martin (1973).

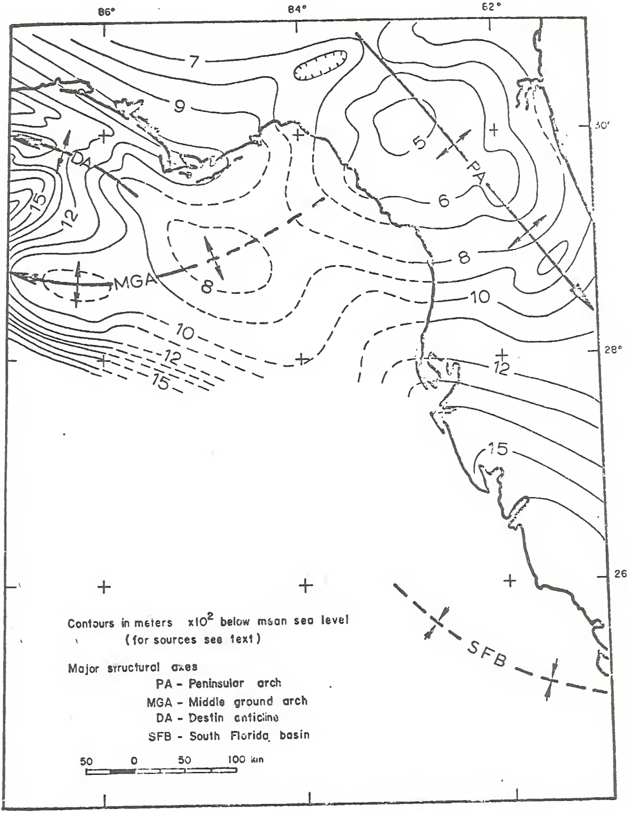
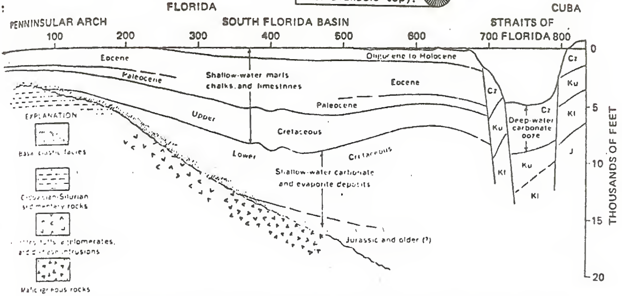
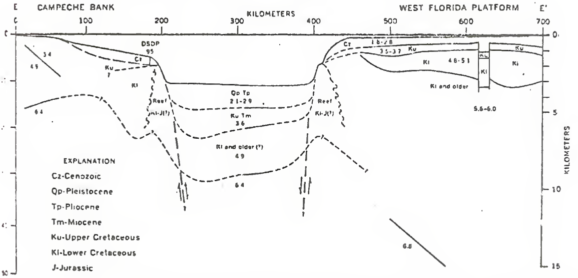


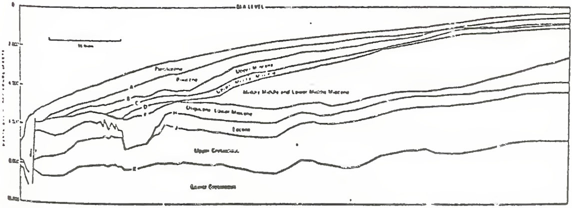

Figure 12. Structure contours on top of Cretaceous (after R. G. Martin).




- 13a. Cross section through Florida and Cuba. Adapted from Emery and Uchupi (1972), Rainwater (1971), and Brooks (1973).




13b. Velocity structure of west Florida platform and eastern Campeche Bank. Modified and compiled from Emery and Uchupi (1972), Antoine and Ewing (1963), Ewing et al. (1960), Oglesby (1965) and Worzel, Bryant, et al. (1973). Abyssal plain stratigraphy from studies by R. G. Martin.




13c. Seismic profile line 126 converted to depth scale in feet. Vertical exaggeration is approximately 20:1 (after Mitchun, 1976).

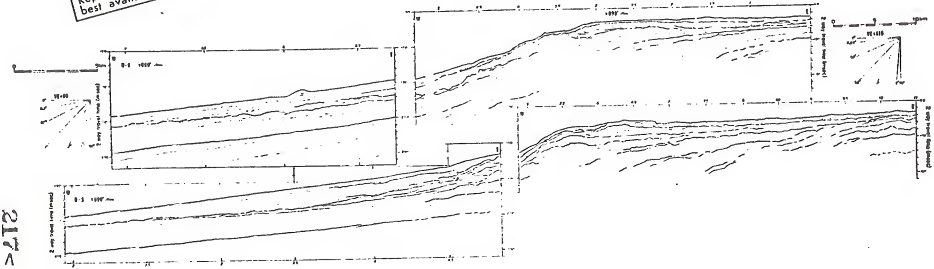


Figure 14. Line tracing of uniboom profile at the outer west Florida shelf and upper slope south of 29°. This area is characterized by a relatively narrow zone of shelf margin, organic skeletal buildups (n.p. 5/4-5, 4/4.5 and possibly at 4/6), a sharp break in the slope (4/4 and 5/5), and moderate angular discordance in pre-pleistocene units (pleistocene approximately 80 msec thick at 5/5.5).

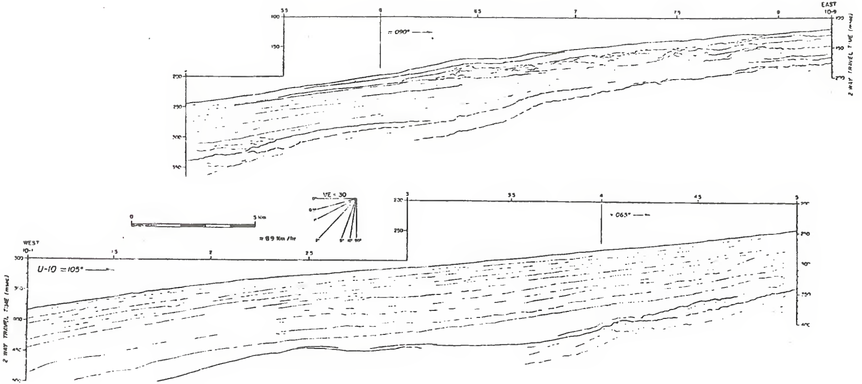



Figure 15. Line tracing of uniboom profile on outer west Florida shelf and upper slope. Broad zones of skeletal buildups appear between 10/6 and 10/7.5, and possibly at 10.4 and 10.5. A complex series of seaward prograding structures is evident at 10.8. An anomalous thickness of post miocene sediments occurs at 10/3.5. Lowest reflector at 10/6 may be top of the upper middle miocene.

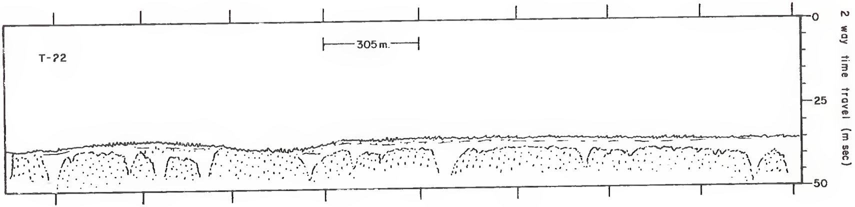



Figure 16. The Big Bend platform (3.5 kHz record) east of the Florida Middle Ground. Dolmen are well developed under thin cover of low-impedence sediment lense.

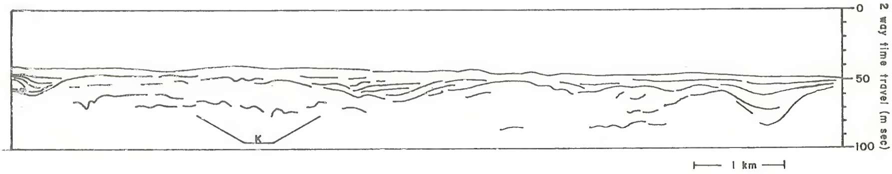



Figure 17 Uniboomer crossing of upper portion of large filled valley system which was detected seaward of Tampa Bay, Florida. Note apparant karstification of lowest reflector at "K". At least three major valleys can be seen at this locality. They converge to the south into one major valley. Filling strata in the valley at the extreme right is 30 msec thick (approximately 20-25 m). Fill character differs markedly between the three structures.

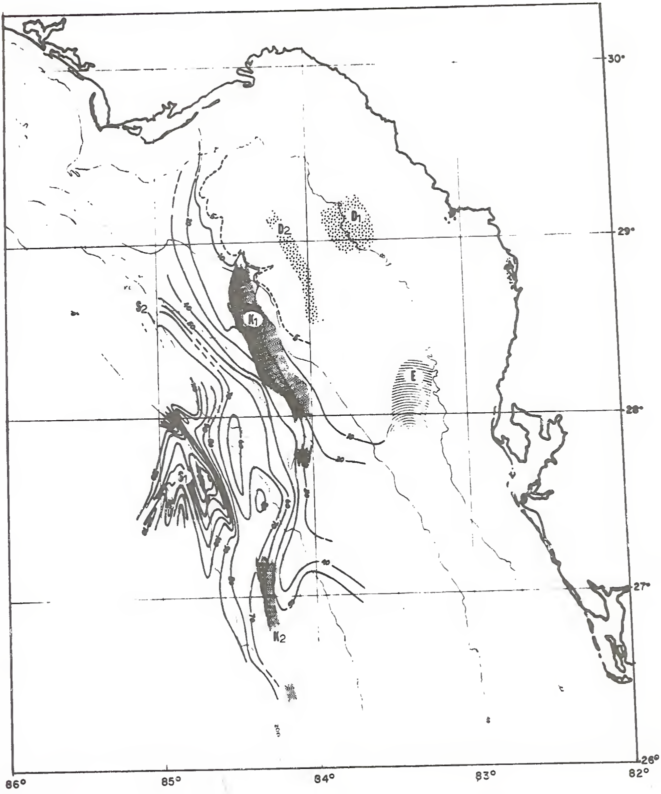
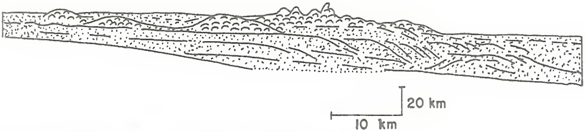
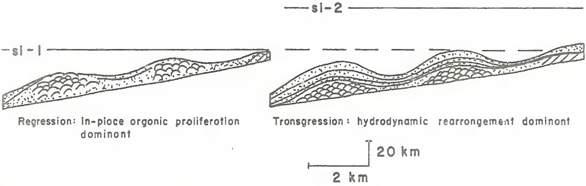


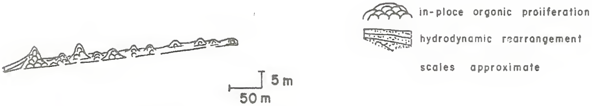

Figure 18. Various subsurface structures located on the peninsular Florida shelf.
$D_1$ and $D_2$ : areas of doline karst features.
$K_1$ and $K_2$ : karren karst trends.
$S_1$ and $S_2$ : slope instability evidenced by creep or slumping.
E : major filled valley complex.
"raw time" : thickness of past Miocene strata given in 10 msec contour intervals.




(a) Longitudinal section -"barrier split" complex.




(b) Shelf margin carbonate buildups.




(c) Outer shelf pinnacle "reefs".

Figure 19. Typical carbonate buildup models found on the west Florida shelf.

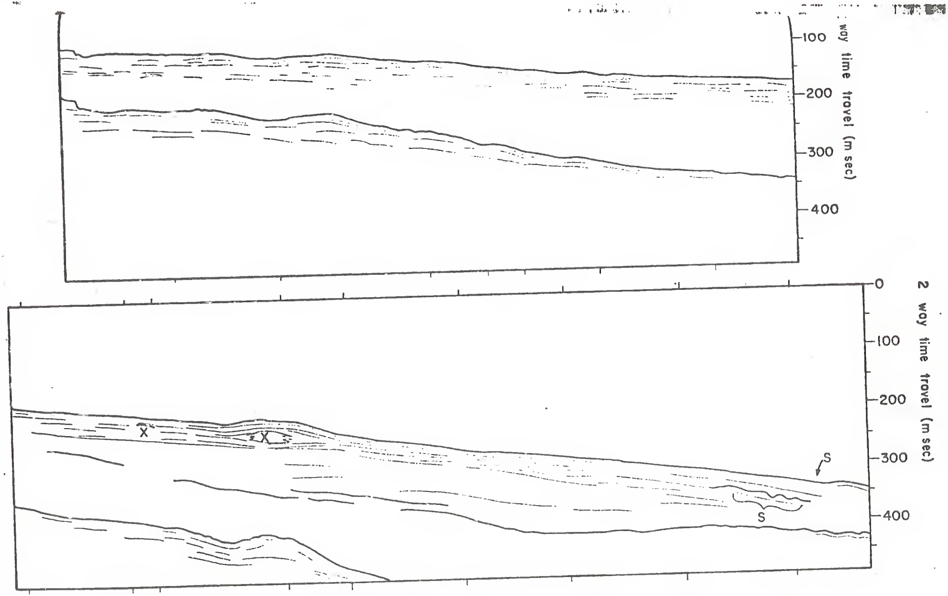



Figure 20. Uniboomer profile of the outer shelf and slope (see line tracing on figure 5).

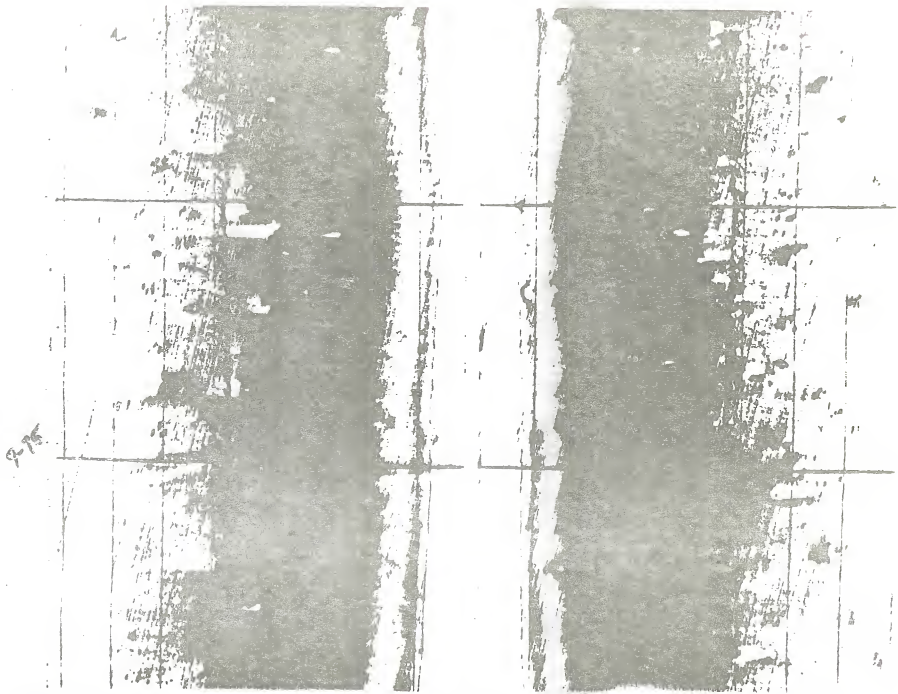


Figure 21. Individual pinnacles seen on profile nine. Depth is 132 m. Relief of most prominent features is approximately two to three meters.

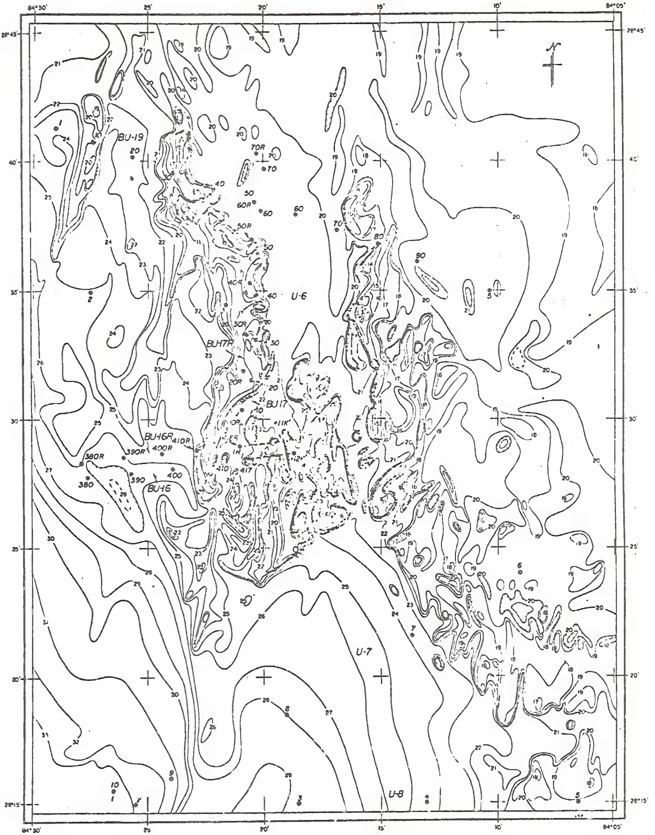



Figure 22. FLORIDA MIDDLE GROUND
(After Jordon, 1952)
One Fathom Contour Interval

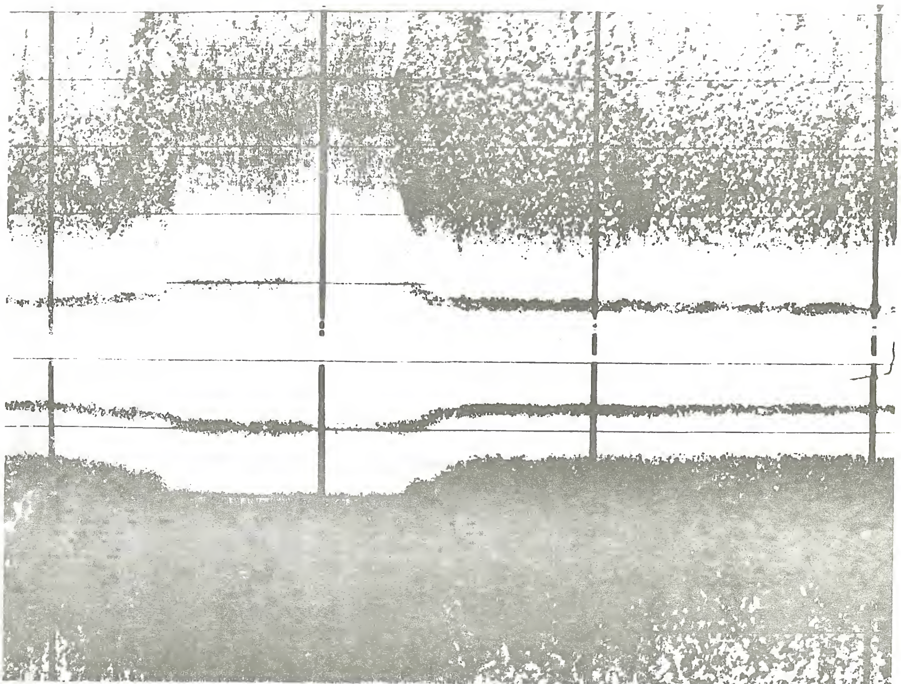


Figure 23. West ridge of Florida Middle Ground, depth is 32 m. Darker area flanking the inner reef pass defines dense flourishing *Millepora*. Smaller "lumpy" signatures indicate less dense communities (gorgonian-sponge flat) on the reef crest.

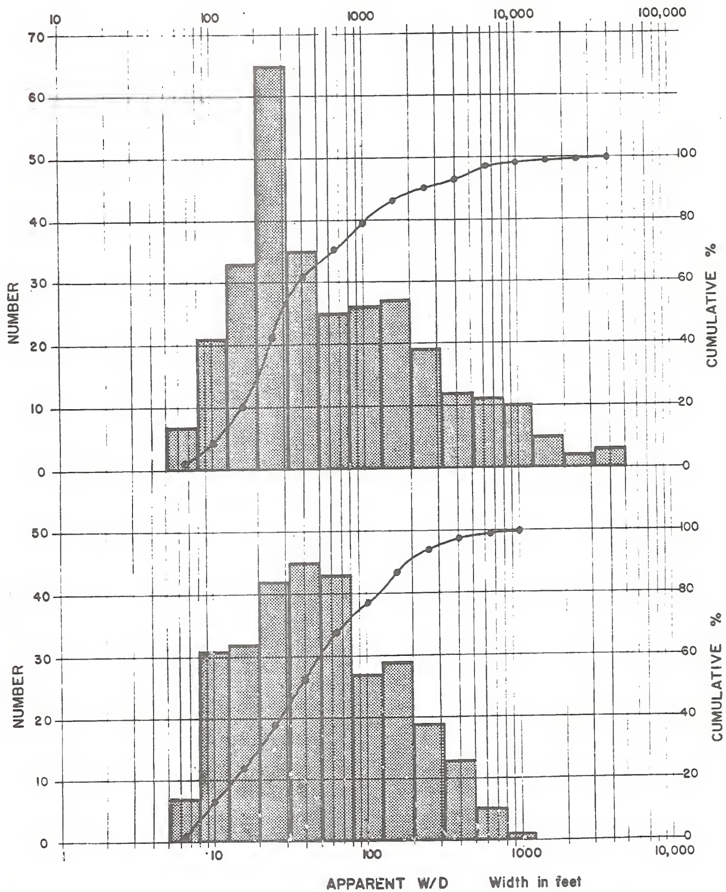



Figure 24. Population vs. dimensional character of negative structures present on the west Florida shelf.

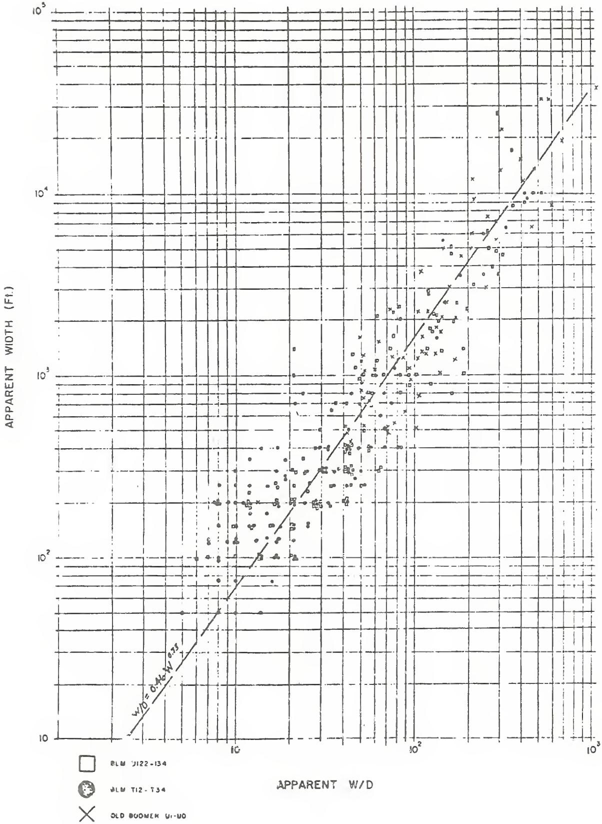
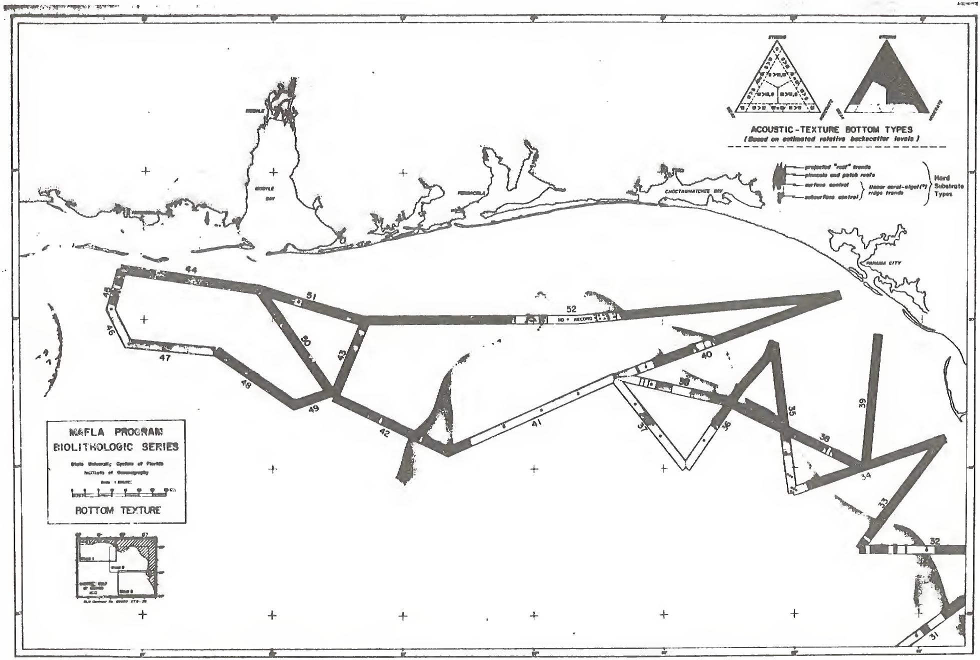
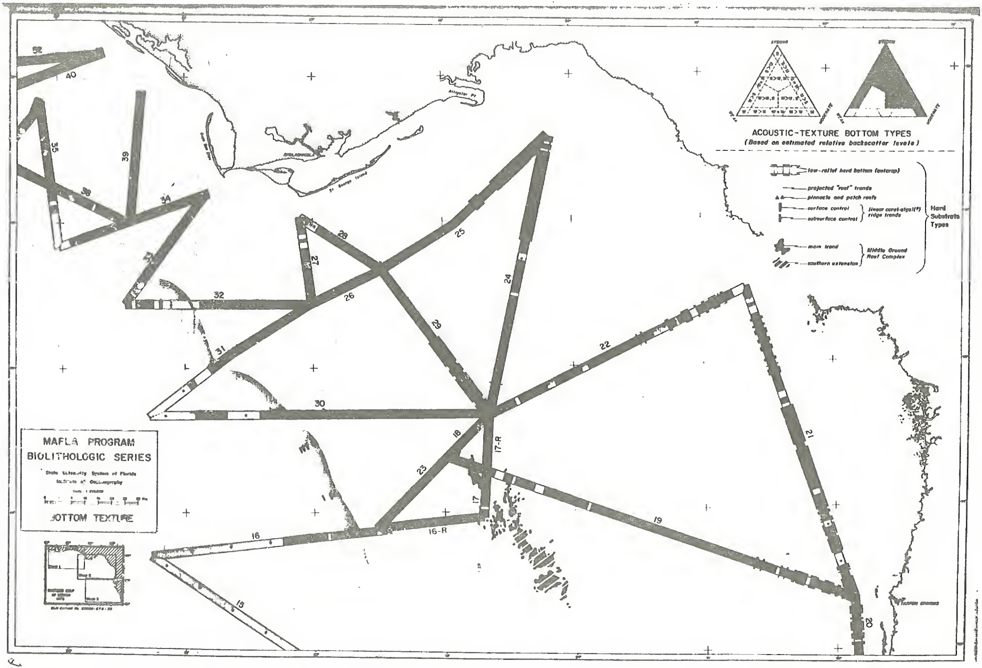



Figure 25. Dimensional characteristics of negative structures present on the west Florida shelf.




229

Figure 26. Bottom texture chart of the MAFLA area, sheet one.




J30

Figure 27. Bottom texture chart of the MAFLA area, sheet two.

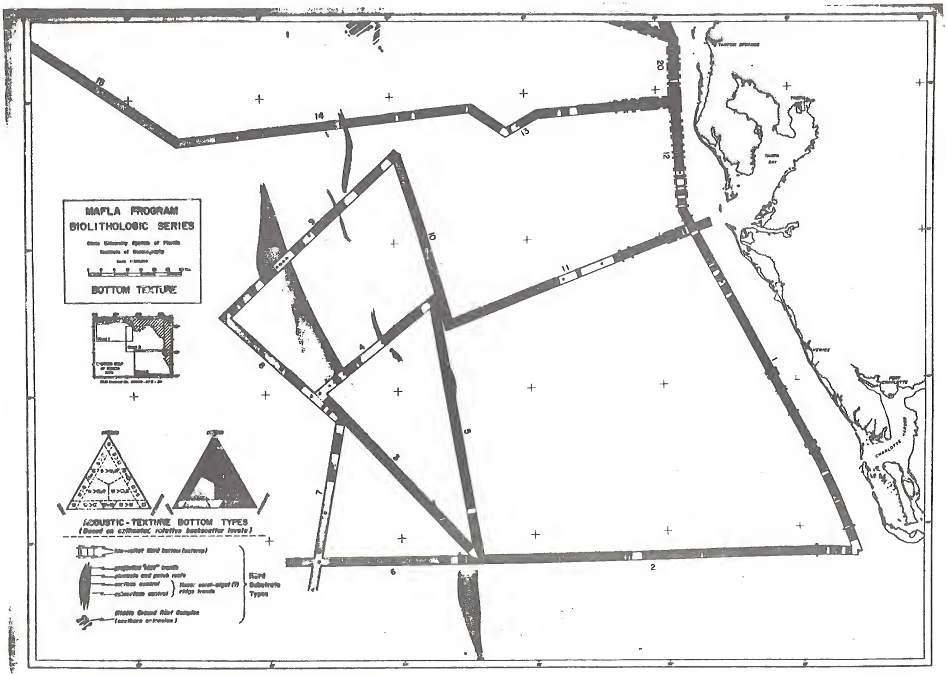
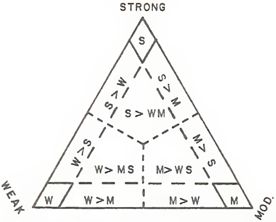
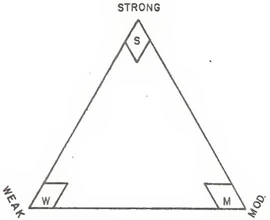


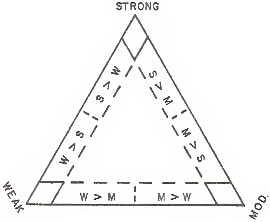

Figure 28. Bottom texture chart of the MAFLA area, sheet three.



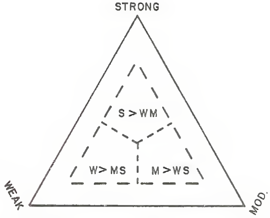

(a) Twelve classes of bottom indicating dominant reverberation level, variability of uniformity and subordinant bottom type.




(b) Three basic levels of backscatter (where mapped, indicates uniform bottom).




(c) Six two-component classes where mapped, basic units occurred in patches too small to show at mapping scale. Dominant and subordinate classes indicated.




(d) Three multicomponent classes where mapped, all three units occurred in patches too small to show at mapping scale. Dominant type indicated.

(e) Fifteen classes used in side scan sonar texture maps (figures 26-28).

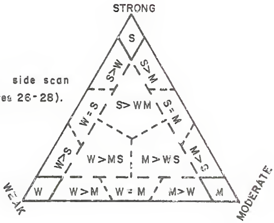



Figure 29. Scheme developed to map relative backscatter levels observed on sonar profiles.

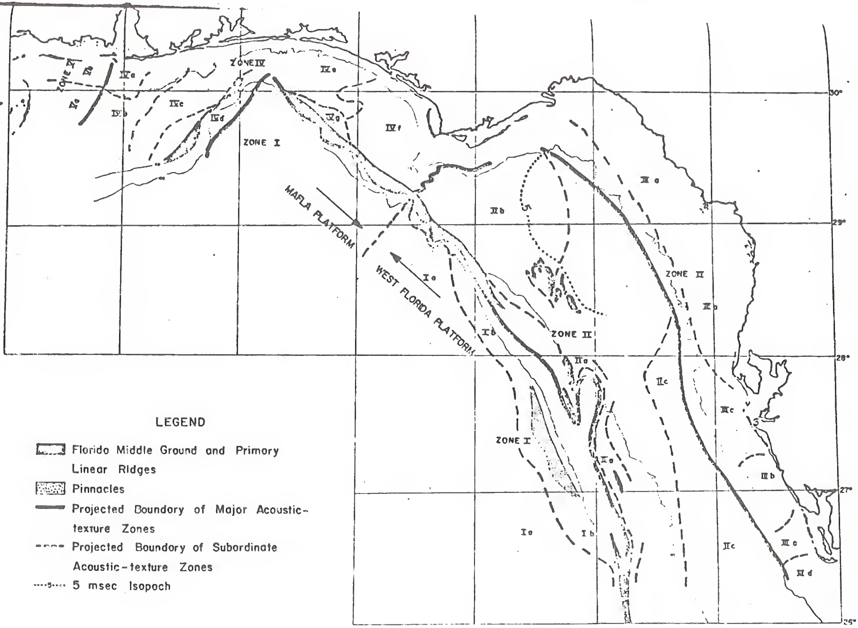
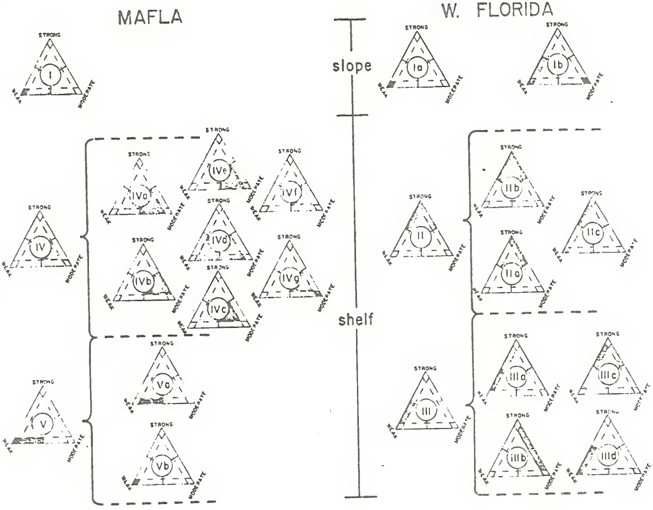



Figure 30. Sketch map of acoustic-texture zones, including major reef trends.




LEGEND

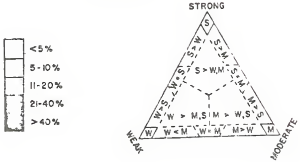



Figure 31. Ternary classification of the MAFLA slope and shelf. The corners (strong, moderate and weak) on each ternary indicate areas of uniform signal. When two or more discrete types were present, estimates were made on dominance of one type over another (S>M indicates patches of strong return are more dominant than moderate tones).

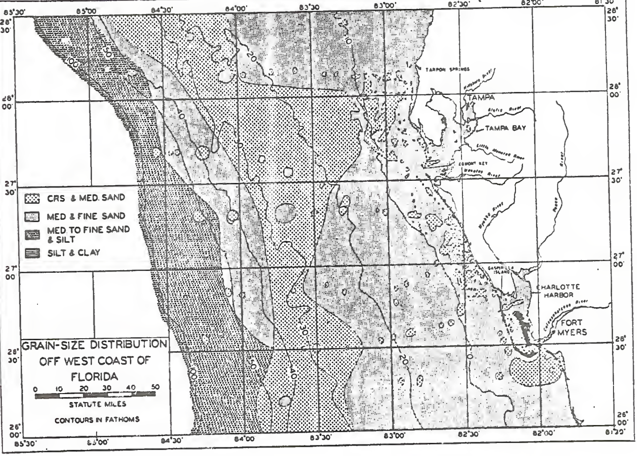



Figure 32 a. Grain size distribution of unconsolidated sediments off the west coast of Florida.

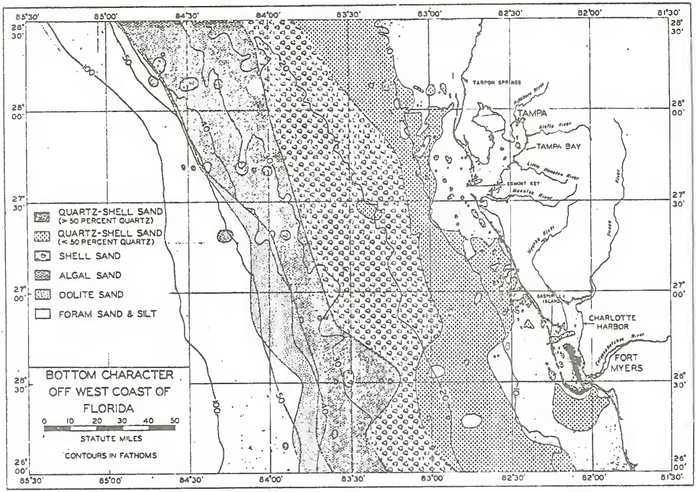



Figure 32b. Classification and distribution of unconsolidated sediments off the west coast of Florida.

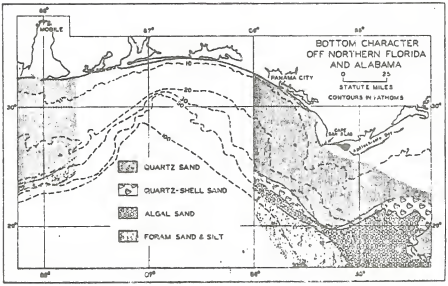



Figure 32c. Classification and distribution of unconsolidated sediments off northern Florida and Alabama.

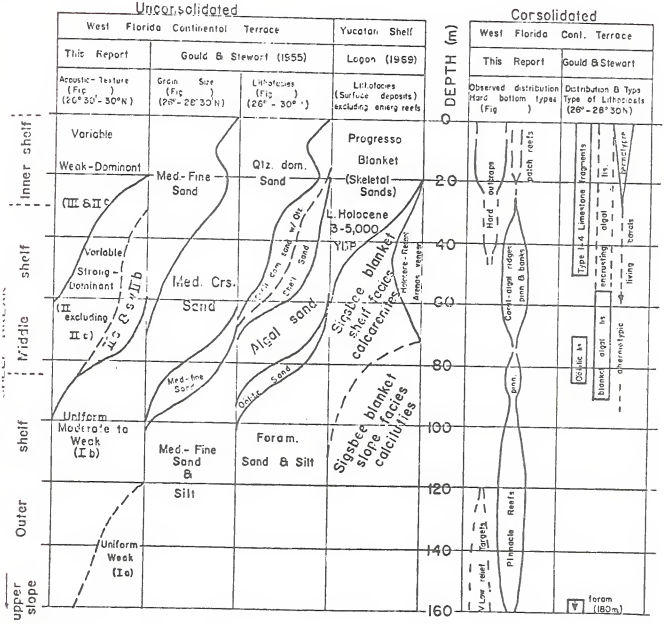
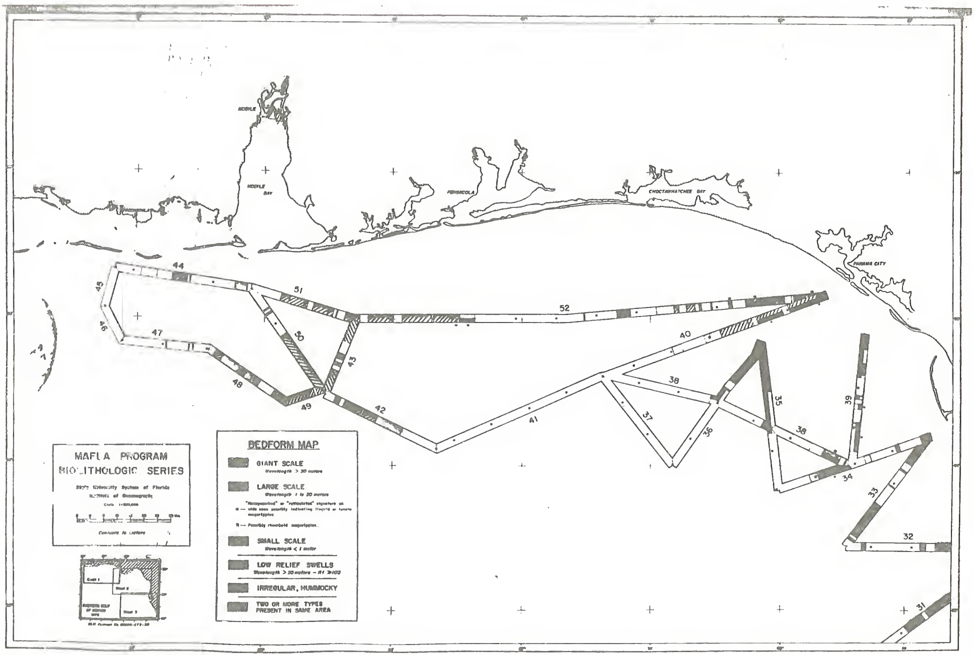
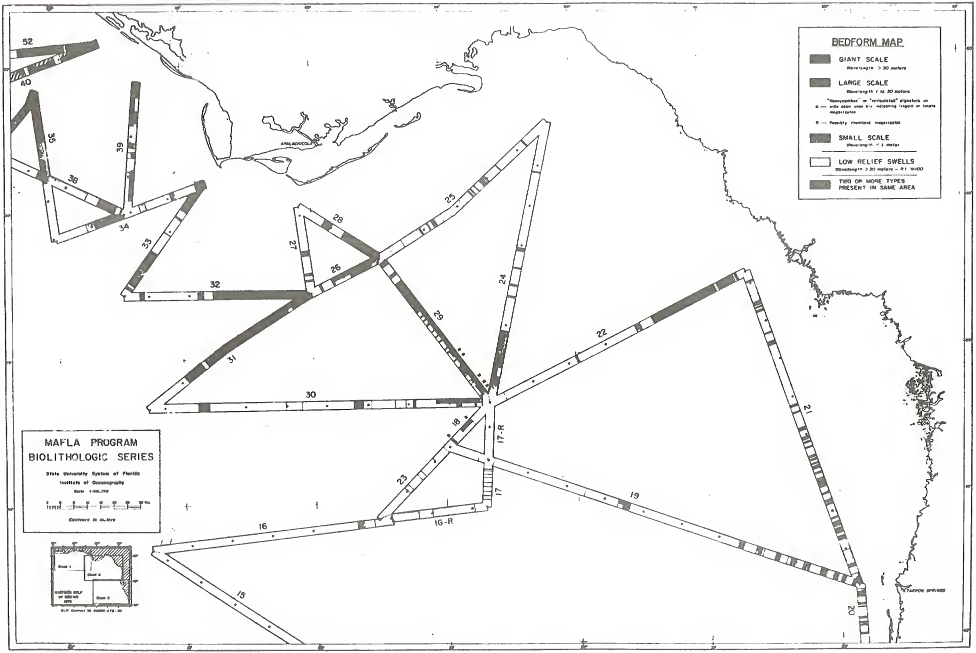



Figure 33. Diagrammatic correlation chart showing observed depth ranges of textural zones, lithofacies and hard bottom types of the west Florida shelf.




23B

Figure 34. Bedform map of the MAFLA area, sheet one.




237

Figure 35. Bedform map of the MAFLA area, sheet two.

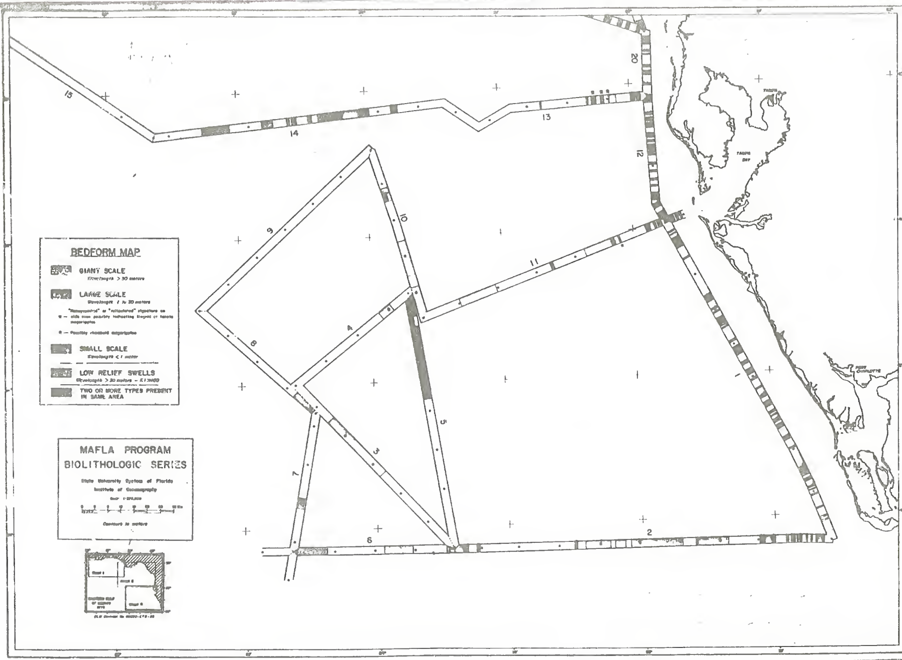



Figure 36. Bedform map of the MAFLA area, sheet three.

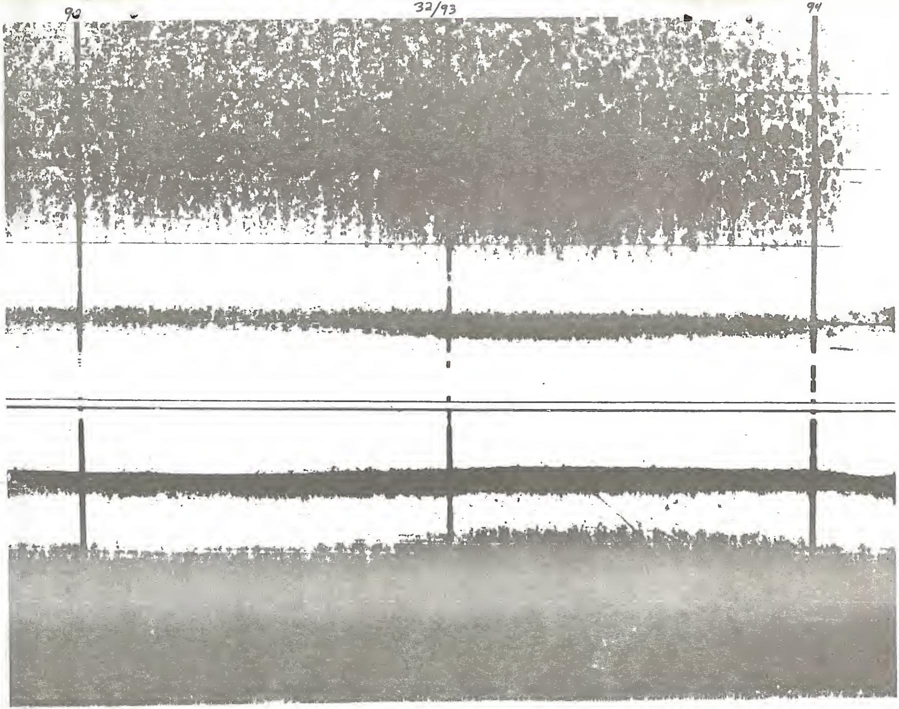



Figure 37. Example of reticulated bedforms. Distance between vertical lines is 305 m. Horizontal lines represent a slant range of 25 m.

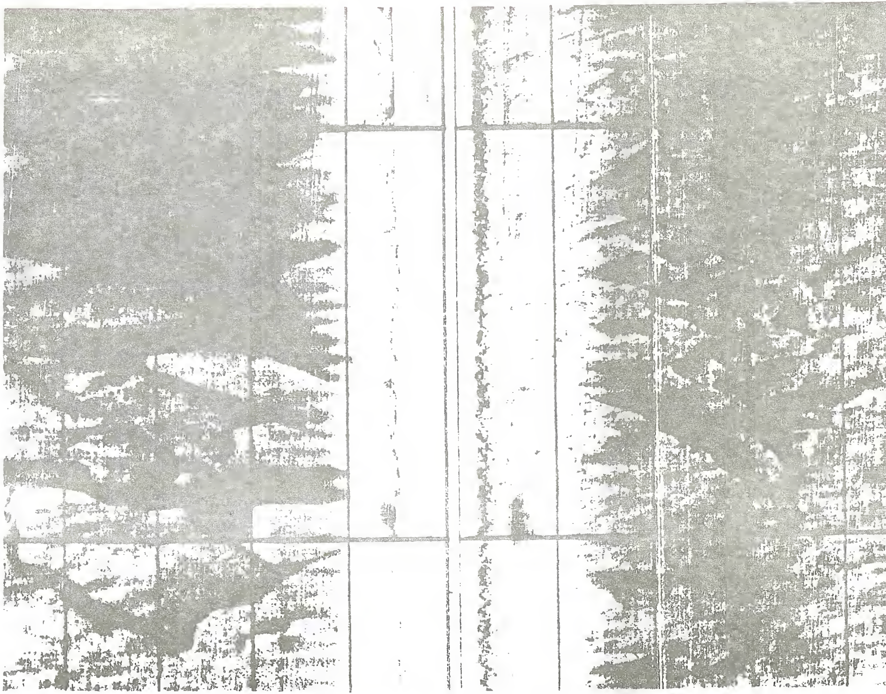
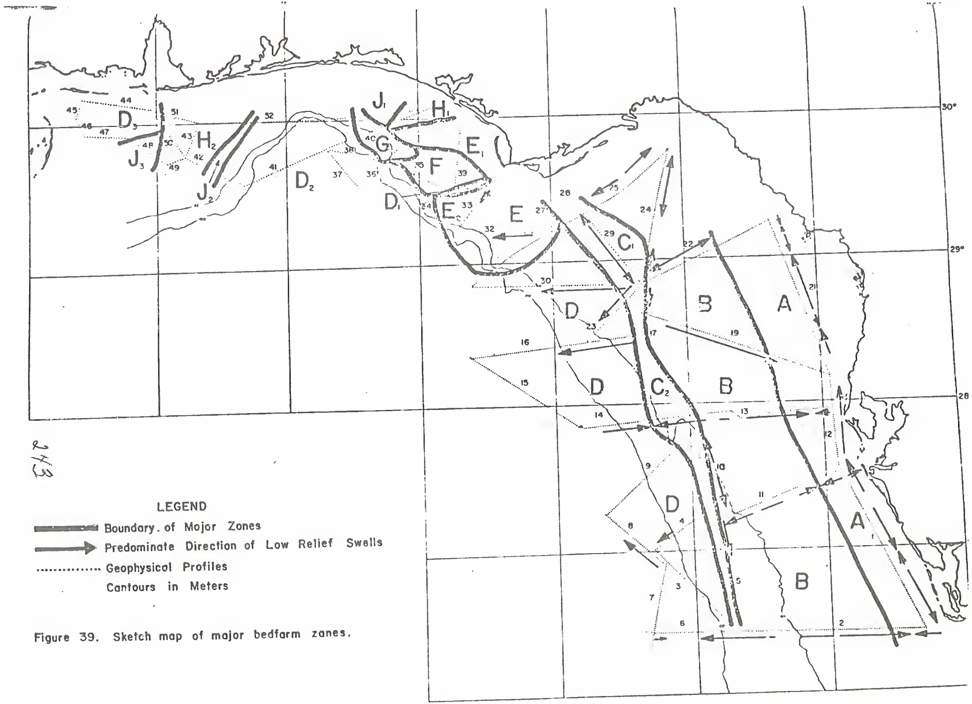


Figure 38. Example of side-scan sonar signature thought to represent rhomboid megaripples in 20 m depth.




243

Figure 39. Sketch map of major bedform zones.

22-57

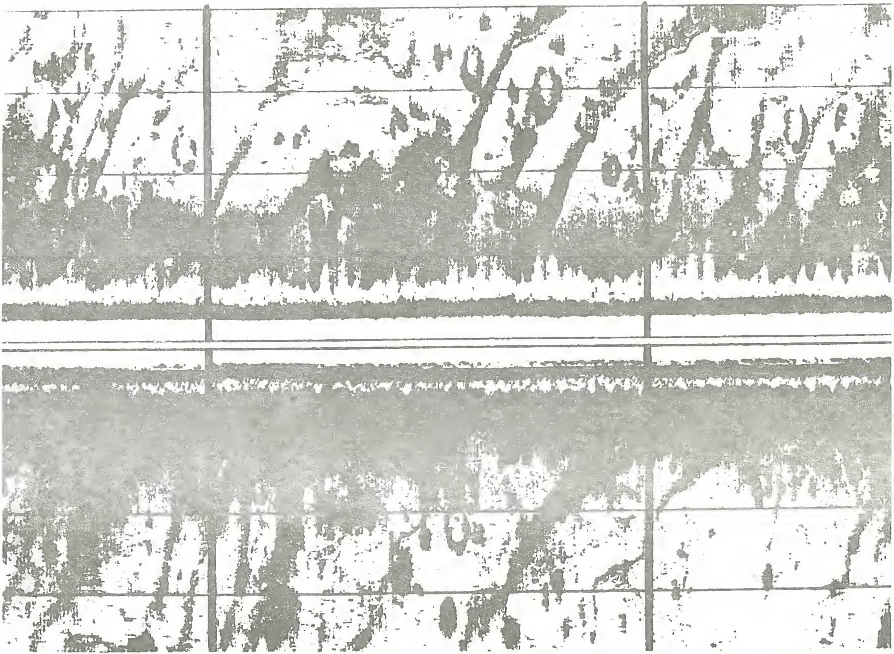


Figure 40. Darker lineations correspond to troughs between giant sand waves (wavelength 30 m, amplitude one m). Unknown biological community evident along flanks (type seven unidentified target). Water depth is 12 m.

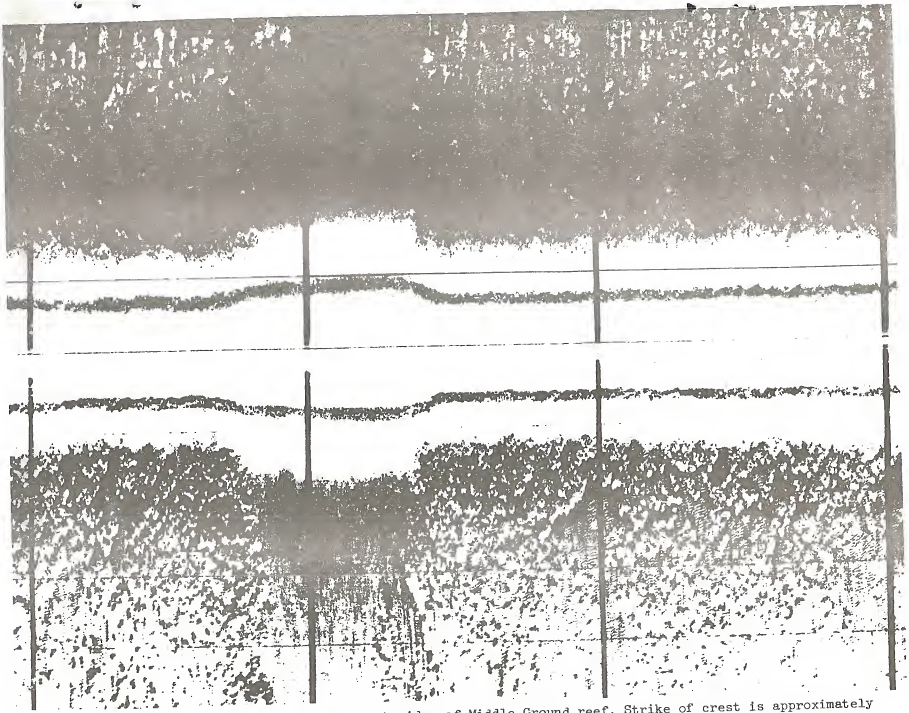


Figure 41. Small scale ripples on crest of west ridge of Middle Ground reef. Strike of crest is approximately NW-SE, depth is 30 m. Darker area flanking the inner-reef pass defines dense flourishing reef community (Millepora ridge). Smaller "lumpy" signatures represent less dense communities.

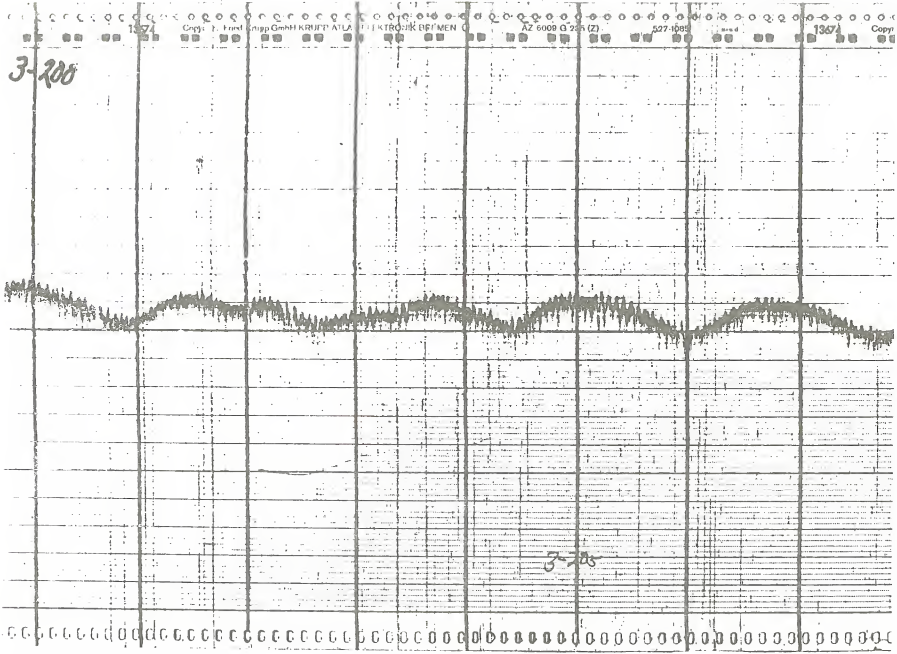



Figure 42. Low relief swells on the outer shelf at depth of 120 m. Average wavelength approximately 450 m, amplitude approximately two m. Vertical lines represent intervals of 305 m, dark horizontal lines equal to two m.

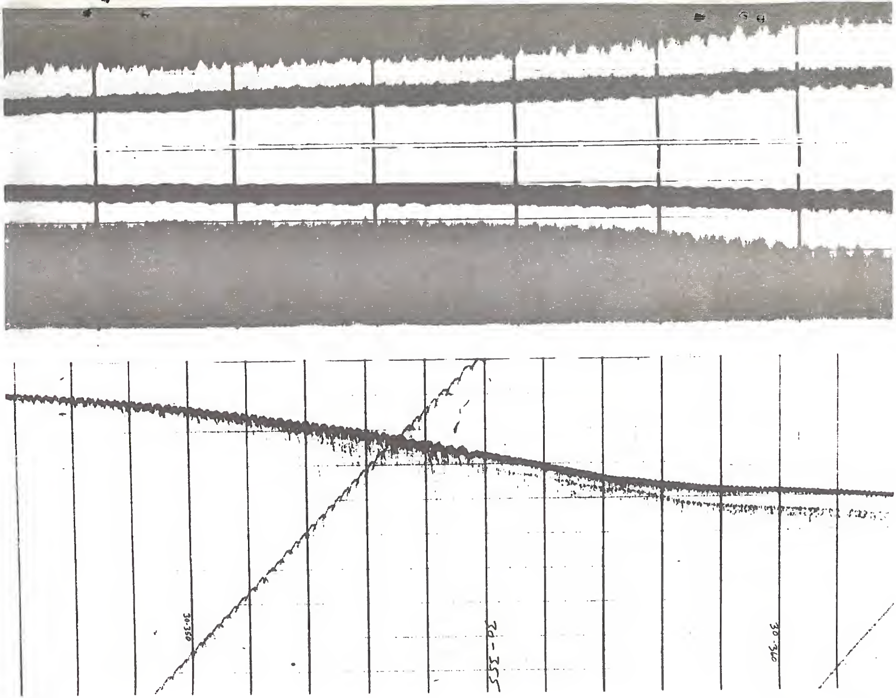



Figure 43. Side-scan sonar and 3.5 kHz profile crossing hyperbolic dunes occurring at depths of 120 m. Note the linearity of the crests which are parallel and the high reflectivity of the bottom on the sonar recording.

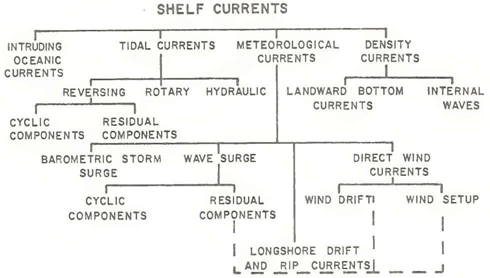



Figure 44. Components of the shelf velocity field (Swift, et. al, 1971).

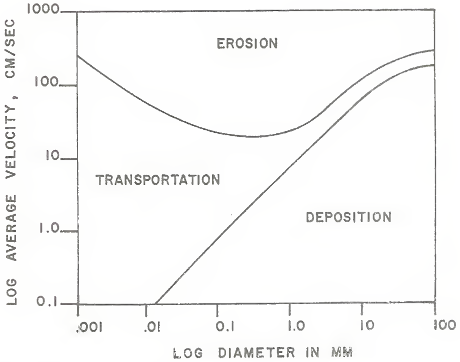



Figure 45. Hjulstrom's diagram of the relations among transportation, erosion, and deposition of sedimentary particles. (Adapted from Hjulstrom, 1939)

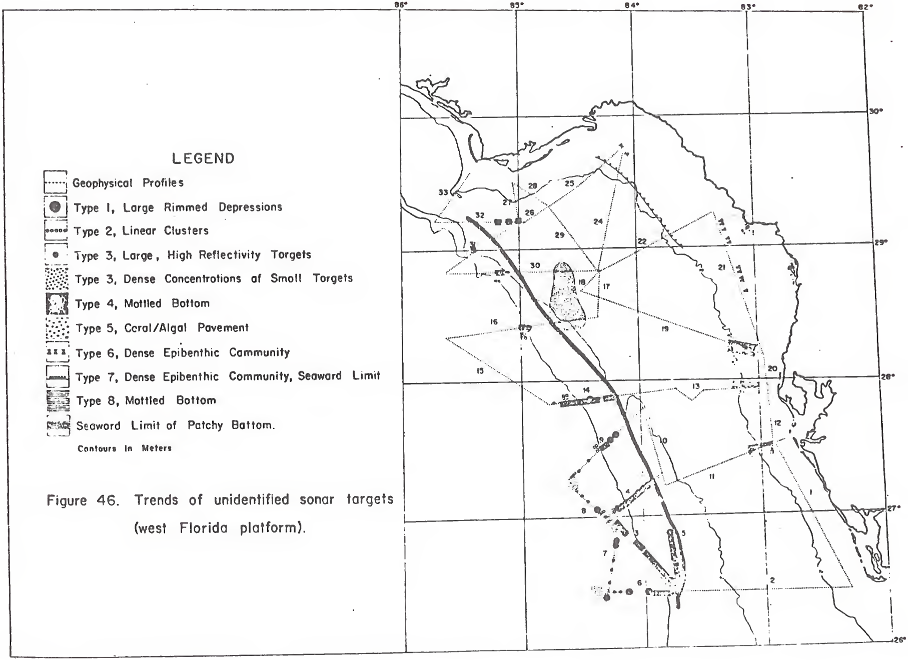



Figure 46. Trends of unidentified sonar targets (west Florida platform).

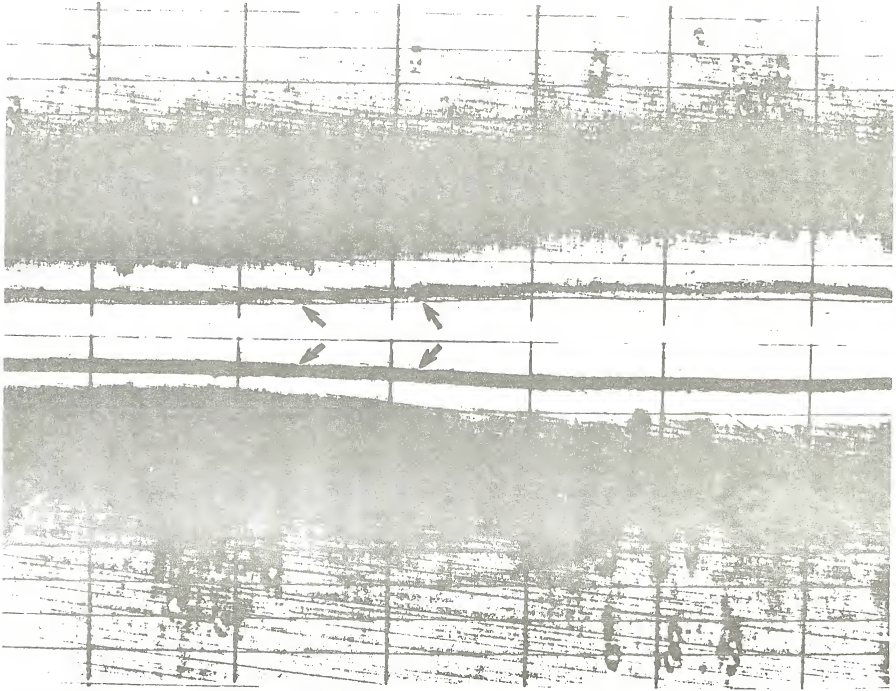


Figure 47. Large depressions at depth of 130 m (type one unidentified target). At arrow note direct crossing indicating approximately two m depth in central depression, example on profile seven.

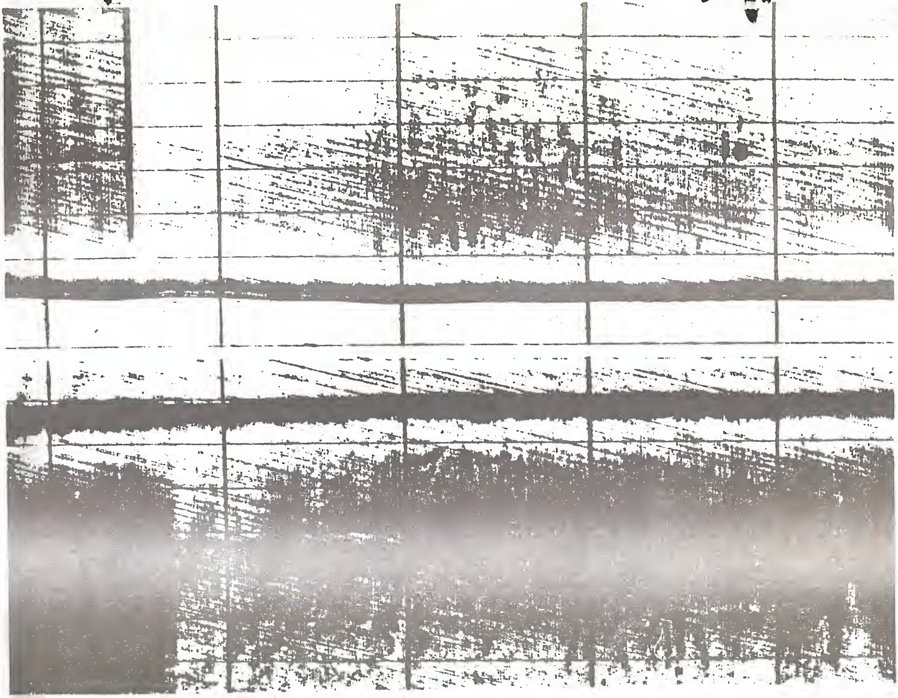


Figure 48. Linear clusters (type two unidentified targets). Depth approximately 135 m, example on profile eight.

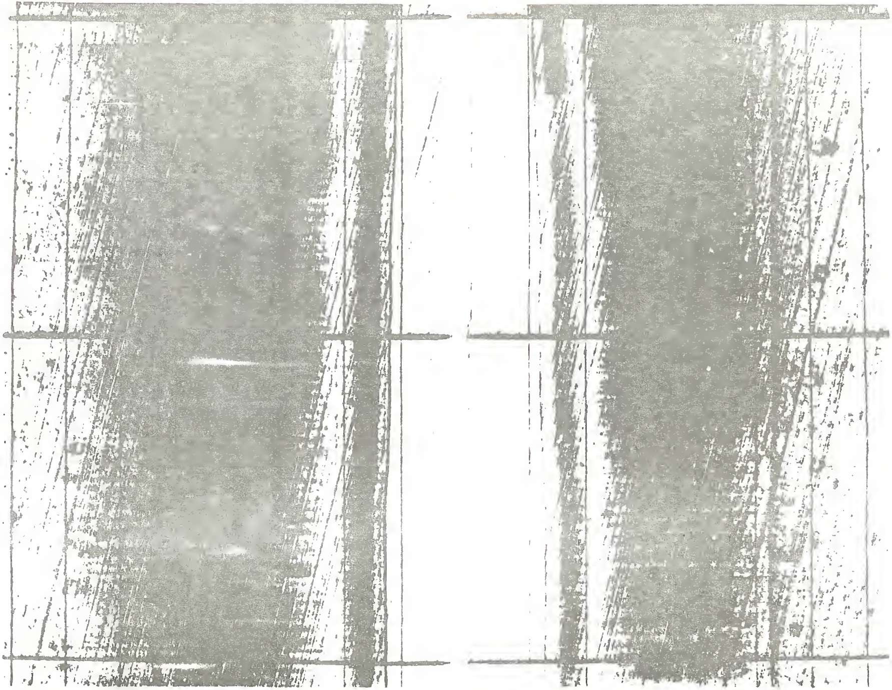


Figure 49. Small targets (type three unidentified targets). Depth approximately 160 m. Acoustic shadow evident indicating slight relief. Example on profile nine.

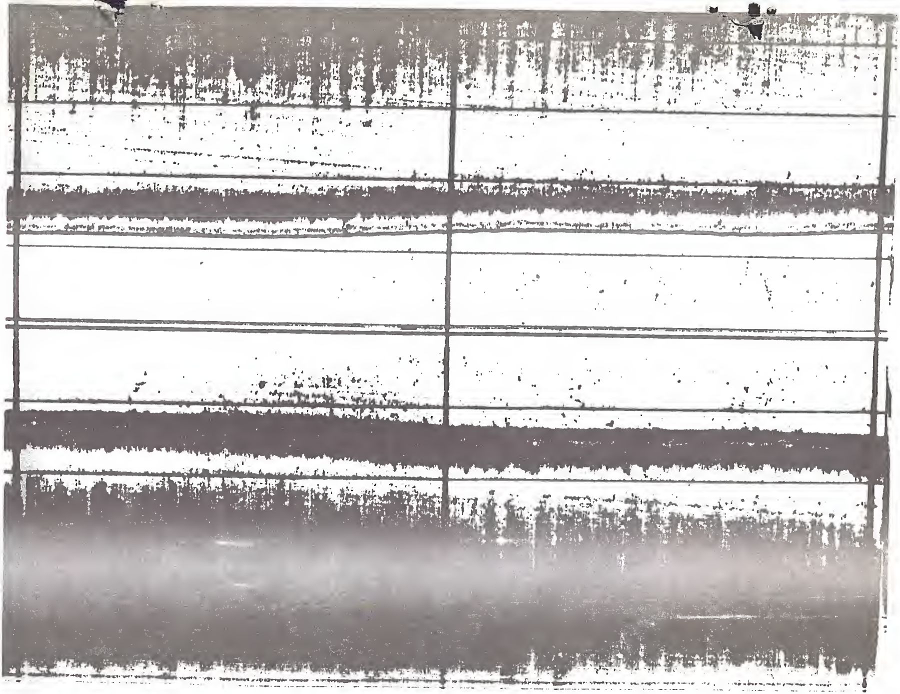


Figure 50. Large targets (type three unidentified targets) in deep water along profile six.

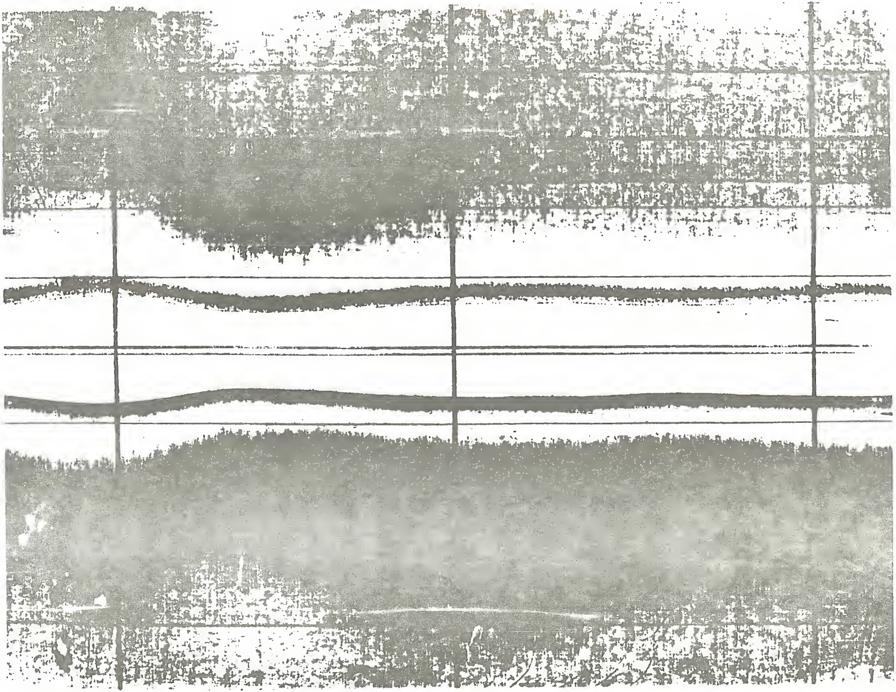


Figure 51. Type four "mottled" bottom, darker material superimposed on lighter matrix. Depth is 85 m along profile five. Note strong targets to the lower left.

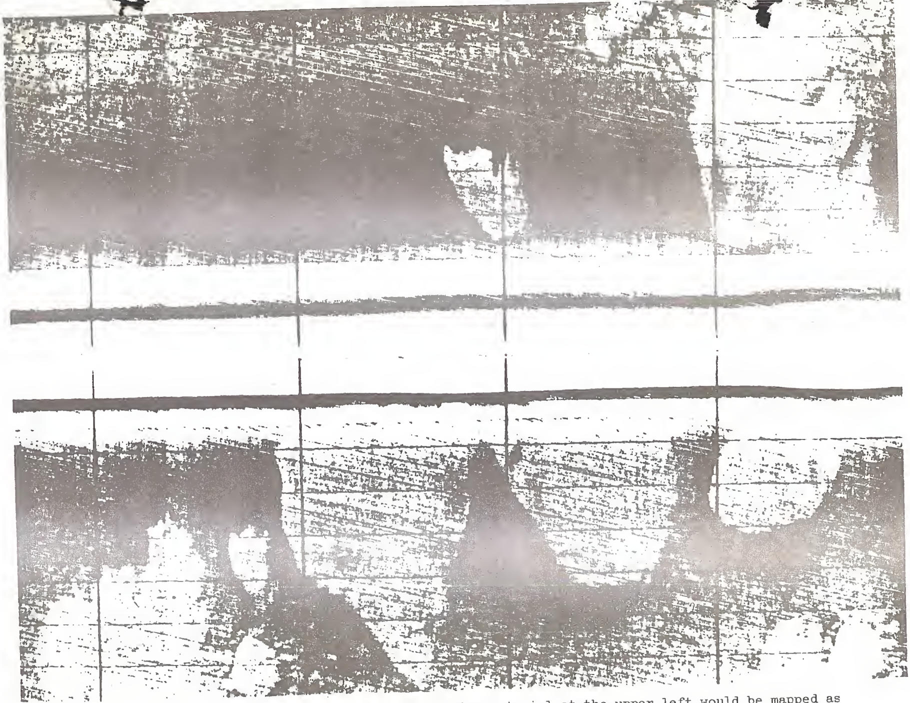


Figure 52. Variable or "patchy" bottom. Higher reflectivity material at the upper left would be mapped as "uniform-moderate" while lower and right hand portions would be mapped as "variable-moderate dominant with weak".

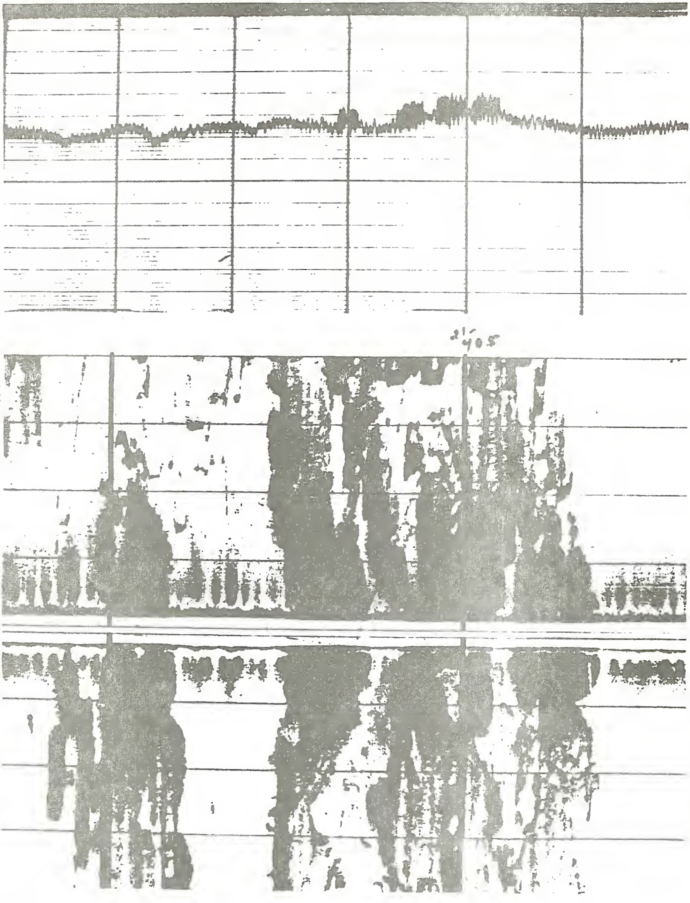


Figure 53a. Section along profile 21 at a depth of eight meters. Mapped as type six (unidentified targets) on figure 46. "Smeared" signature believed to be dense epibenthic community.

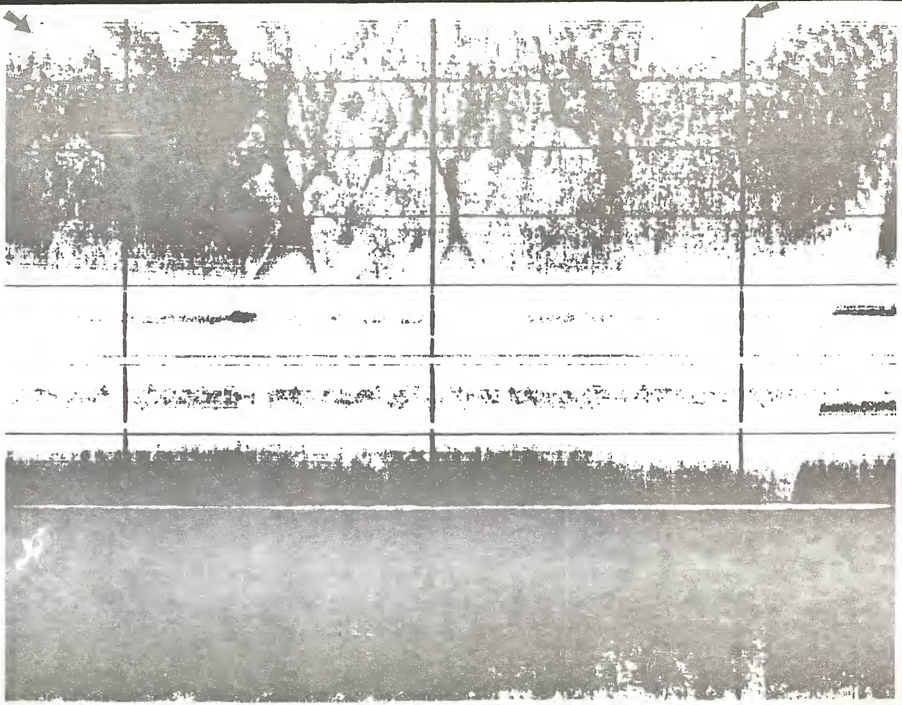


Figure 54. Type eight "mottled" bottom (between arrows), profile number 13, depth of 20 m.

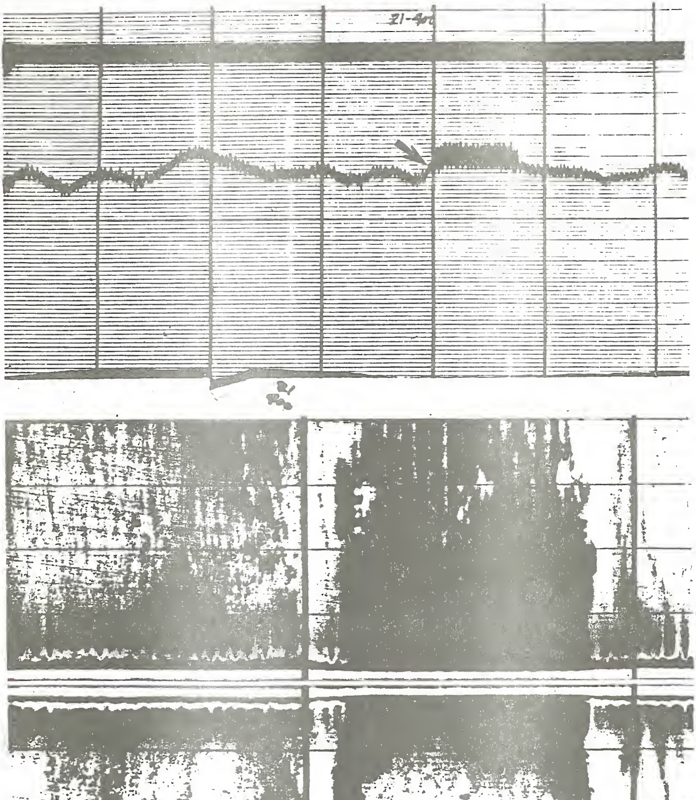


Figure 53b. Another example of type six (unidentified targets). On profile 21 at eight meters depth, note rocky looking signature at arrow on sonar record corresponding to trough on PDR.